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Technical Sciences

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DEVELOPMENT OF A PPO-BASED MODEL FOR OPTIMIZING INDUSTRIAL ENERGY CONSUMPTION

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Abstract. The article considers a reinforcement learning model for optimizing industrial energy consumption using the Proximal Policy Optimization (PPO) algorithm. The proposed approach is aimed at supporting energy management decisions under variable production demand, dynamic electricity prices, equipment condition constraints and the availability of local generation and battery storage. The energy management task is formulated as a Markov decision process, where the state space includes production load, energy price, solar generation, battery state, equipment health and demand indicators. The action space is represented by a continuous control vector for changing equipment load levels, while the reward function combines energy cost reduction, demand satisfaction and equipment health preservation. The model is tested in the IndustrialEnergyEnv simulation environment and compared with a baseline control scenario. The results show that the PPO-based model can reduce total energy consumption and economic cost; however, additional reward balancing is required to ensure full production demand satisfaction.

Keywords: energy management; industrial automation; reinforcement learning; PPO; SCADA; simulation environment; optimization; energy consumption.

1. Introduction

Efficient use of energy resources is one of the key conditions for reducing production costs and improving the reliability of industrial enterprises. In many production facilities, energy consumption is directly related to equipment operating modes, technological load, production schedules and the price of electricity. Therefore, energy management should not be considered only as a metering or reporting function. It should become a data-driven control task that supports operational decision-making [1].

Traditional energy management approaches are often based on predefined rules, periodic reporting, operator experience or static optimization. Such approaches can be effective under stable operating conditions, but they are not always flexible enough for modern industrial environments. Production demand, electricity tariffs, local generation, battery state and equipment condition may change at the same time. As a result, the energy management system must be able to adapt to changing conditions and select control actions based on the current state of the enterprise.

Reinforcement learning is one of the promising methods for solving such sequential control problems. In this approach, an agent observes the state of the environment, selects an action and receives a reward that reflects the quality of the selected decision [2]. Over time, the agent

improves its policy and learns to select actions that provide better long-term results. This logic is suitable for industrial energy management, where a locally beneficial decision may have negative consequences in the future.

The purpose of this article is to develop a PPO-based model for optimizing industrial energy consumption and to evaluate it in a simulation environment by comparison with a baseline control scenario.

2. Formulation of the Energy Management Problem

In this study, the energy management problem is represented as a Markov decision process [2]. This representation makes it possible to describe the interaction between the control agent and the industrial energy environment through a set of states, actions, transition rules and rewards. In general form, the model is written as follows:

$$\mathbf{M} = \langle \mathbf{S}, \mathbf{A}, \mathbf{P}, \mathbf{R}, \gamma \rangle, \quad (1)$$

where S is the set of states, A is the set of actions, P is the transition mechanism between states, R is the reward function and γ is the discount factor that determines the importance of future rewards.

The state space includes both energy and production parameters. In the proposed model, the state vector contains information about production load, equipment health, electricity price, solar generation, battery state and current production demand. This allows the agent to evaluate energy consumption not as an isolated numerical value, but as part of the overall production context.

The action space is defined as a continuous control vector that changes the load levels of production equipment. The agent must not only reduce energy consumption, but also avoid excessive equipment degradation and maintain the required production output. This makes the task multi-objective and more realistic for industrial applications.

The reward function combines several components: reduction of electricity cost, reduction of grid energy consumption, satisfaction of production demand, preservation of equipment health and limitation of inefficient load peaks. Therefore, the model is not aimed at simple energy saving only. It is designed to search for a balance between energy efficiency, production performance and operational reliability.

Table 1. Main indicators used for model evaluation

No.	Indicator	Unit	Description
1	Total economic cost	KZT	Cost of energy purchased from the external grid
2	Energy consumption	kWh	Total energy consumed during the simulation
3	Demand satisfaction	%	Degree of fulfilment of production demand
4	Peak-to-average ratio	ratio	Ratio of peak power to average power
5	Average power	kW	Average load level of the system
6	Total reward	units	General performance indicator of the RL policy

3. PPO-Based Control Model

The Proximal Policy Optimization algorithm was selected because it is suitable for control tasks with continuous action spaces and provides stable policy updates. PPO limits excessive policy changes during training and therefore reduces the risk of unstable control behavior. This is important for industrial energy management, where abrupt changes in equipment load may affect production quality, equipment reliability and energy consumption dynamics [3].

The PPO algorithm is based on the actor–critic architecture. The actor selects the control action, while the critic evaluates the quality of the selected action. This structure allows the agent to learn not only from immediate energy savings, but also from the expected long-term effects of its decisions. In the proposed model, the PPO agent receives the current state of the industrial energy system and generates control actions that define the load levels of production equipment.

The general architecture of the proposed system includes the industrial data acquisition layer, the preprocessing module, the simulation environment, the PPO agent and the analytical layer. Data may be received from sensors, meters, PLC and SCADA systems [6]. After preprocessing, the information is transferred to the RL-based decision-making module. The resulting control strategy can be further integrated with SCADA, ERP or business intelligence platforms [7].

Structural diagram of the IndustrialEnergyEnv simulation environment for training an RL model

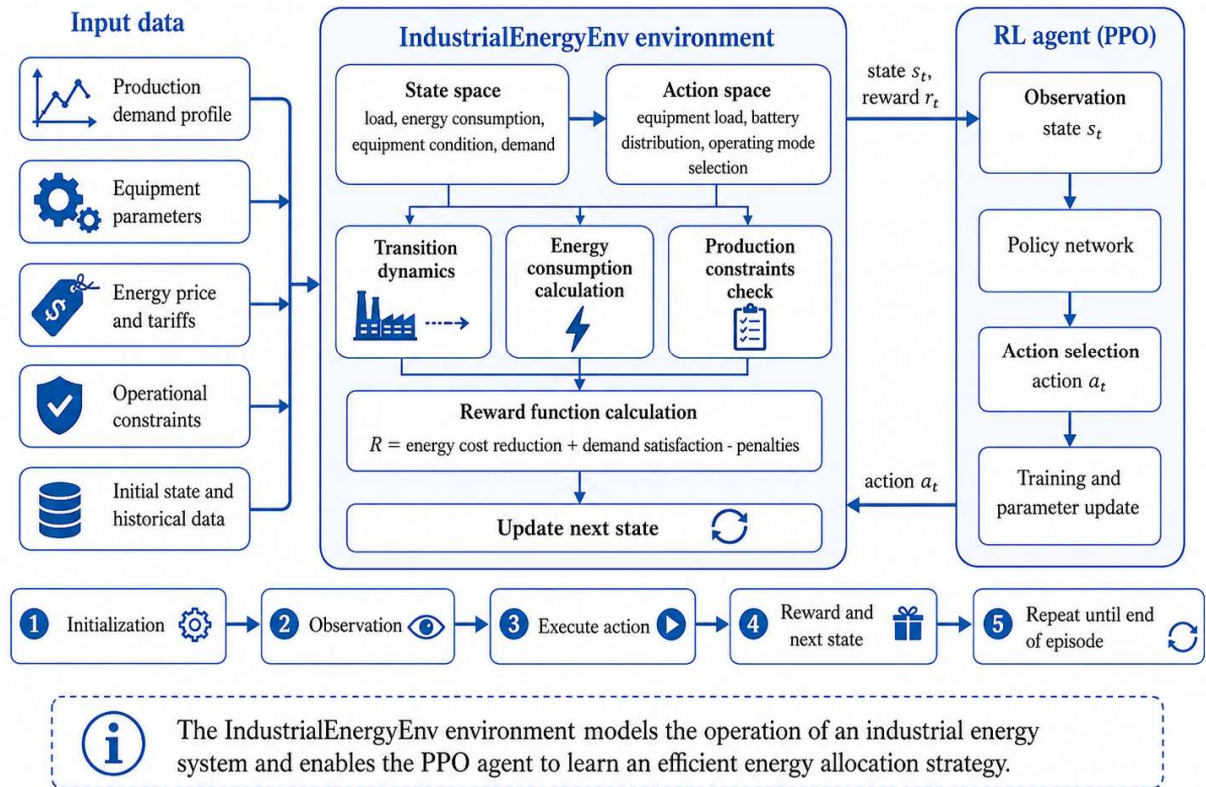


Figure 1. Structure of the IndustrialEnergyEnv simulation environment for PPO agent training

4. Simulation Environment

The proposed model was tested in the IndustrialEnergyEnv simulation environment. The environment was designed to imitate the energy consumption process of an industrial workshop without direct influence on a real production facility. Such an approach is useful for testing reinforcement learning algorithms, because it allows the agent to explore different scenarios without creating risks for actual equipment or production processes.

The simulation model represents a glass unit production workshop with several key technological machines. The environment includes equipment power, working modes, electricity tariffs, solar generation, battery state and production demand. At each time step, the agent observes the current state, selects an action, and the environment returns a new state and reward value.

The pilot object structure used in the simulation is shown in Figure 2. The scheme demonstrates the relationship between production equipment, energy supply sources, battery storage, monitoring systems and the decision-making module.

Technological and Energy Structure of the Pilot Production Facility

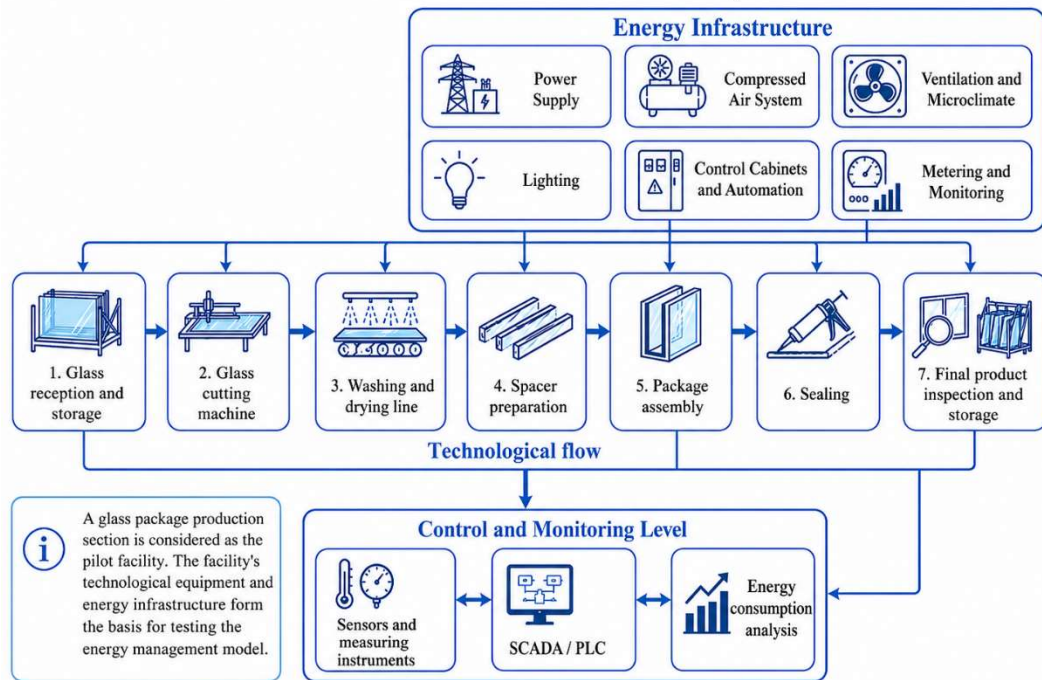


Figure 2. Technological and energy structure of the pilot production object

5. Results and Discussion

The PPO-based control scenario was compared with a baseline control scenario. Both scenarios were tested under the same simulation conditions. The comparison was carried out using total economic cost, total energy consumption, demand satisfaction, peak-to-average ratio, average power and total reward.

Table 2. Comparative results of the baseline and PPO scenarios

Indicator	Baseline scenario	PPO scenario	Difference
Total cost, KZT	22,563.2	5,685.77	-74.8%
Energy consumption, kWh	921.4	392.1	-57.4%
Demand satisfaction, %	100	47.9	-52.1%
Peak-to-average ratio	1.1	1.7	worse
Average power, kW	38.4	16.3	lower
Total reward	-28.9	-18.6	+10.3

The results show that the PPO agent significantly reduced both total cost and energy consumption. Compared with the baseline scenario, total economic cost decreased by 74.8%, while total energy consumption decreased by 57.4%. This confirms that the agent learned to reduce energy use and limit the amount of energy purchased from the external grid.

At the same time, the results also reveal an important limitation. Demand satisfaction decreased from 100% in the baseline scenario to 47.9% in the PPO scenario. This means that the agent gave excessive priority to energy saving and did not sufficiently maintain production demand. Thus, the current version of the reward function does not fully balance energy efficiency and production performance.

The increase in the peak-to-average ratio from 1.1 to 1.7 also requires attention. It indicates that the load was not evenly distributed during some time intervals. Therefore, future versions of the model should include additional penalty terms for peak loads and stronger constraints on production demand satisfaction.

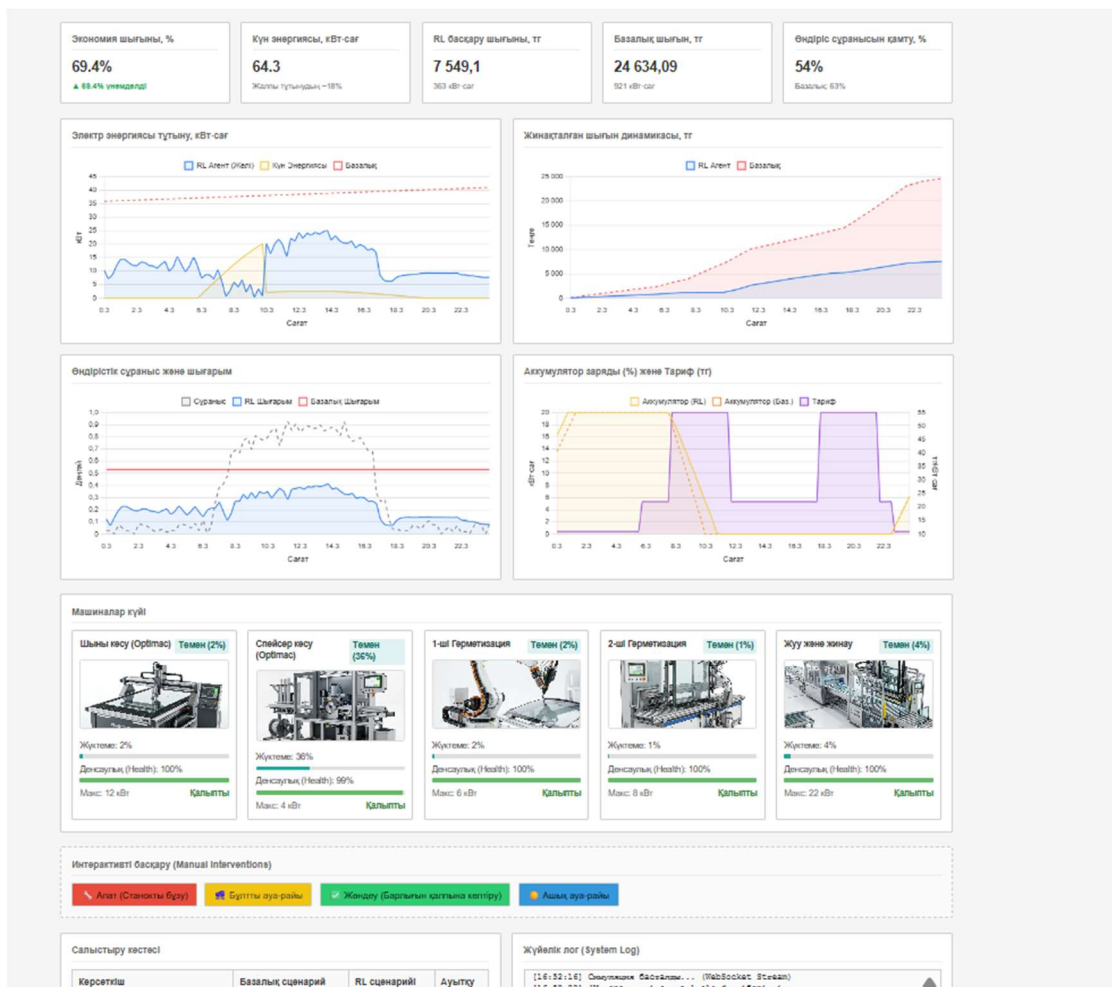


Figure 3. Dashboard and performance graphs of the PPO-based energy management system

Conclusion

This article presented a PPO-based model for optimizing industrial energy consumption. The energy management task was formulated as a Markov decision process, and the main elements of the model, including the state space, action space and reward function, were defined. The model was tested in the IndustrialEnergyEnv simulation environment and compared with a baseline control scenario.

The obtained results show that the PPO-based model can reduce total energy consumption and economic cost. However, the decrease in production demand satisfaction indicates that the reward function must be further improved. In real industrial applications, energy saving should not lead to the violation of production requirements. Therefore, the proposed model should be considered not as a ready-to-deploy industrial solution, but as a simulation-based prototype for intelligent industrial energy management.

Future research should focus on reward function balancing, integration with real SCADA data, the development of a test stand and comparison of PPO with other reinforcement learning algorithms such as DQN, A2C and SAC [2, 5].

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6. IEC 62541. OPC Unified Architecture.
7. IEC 62443. Industrial communication networks – Network and system security.

Аннотация. В статье рассматривается модель оптимизации промышленного энергопотребления на основе метода обучения с подкреплением с применением алгоритма Proximal Policy Optimization (PPO). Предлагаемый подход направлен на поддержку принятия решений в системе энергетического менеджмента в условиях изменяющегося производственного спроса, динамических цен на электроэнергию, ограничений, связанных с техническим состоянием оборудования, а также наличия локальной генерации и аккумуляторного накопителя. Задача управления энергопотреблением формулируется как марковский процесс принятия решений, где пространство состояний включает производственную нагрузку, цену энергии, солнечную генерацию, состояние аккумулятора, техническое состояние оборудования и показатели спроса. Пространство действий представлено непрерывным вектором управления для изменения уровней загрузки оборудования, а функция вознаграждения объединяет снижение энергетических затрат, удовлетворение производственного спроса и сохранение технического состояния оборудования. Модель протестирована в симуляционной среде IndustrialEnergyEnv и сравнена с базовым сценарием управления. Полученные результаты показывают, что PPO-ориентированная модель способна снизить общее энергопотребление и экономические затраты; однако для полного удовлетворения производственного спроса требуется дополнительная балансировка функции вознаграждения.

Ключевые слова: энергетический менеджмент; промышленная автоматизация; обучение с подкреплением; PPO; SCADA; симуляционная среда; оптимизация; энергопотребление.

Methods and Technologies for Evaluating the Effectiveness of Logistics Management Processes in Corporate Information Systems

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Abstract

The systematic evaluation of logistics management processes within corporate information systems (CIS) represents a foundational operational requirement for enterprises seeking to maintain competitiveness in increasingly complex supply chain environments. Despite widespread deployment of Enterprise Resource Planning (ERP), Warehouse Management System (WMS), and Transportation Management System (TMS) platforms, organizations frequently lack the structured methodological apparatus necessary to assess process effectiveness beyond reactive financial reporting. This article presents a comprehensive analysis of the methods and technologies applicable to logistics CIS evaluation, integrating canonical IS success frameworks, specifically the DeLone and McLean IS Success Model, the Balanced Scorecard, and the Supply Chain Operations Reference (SCOR) model, with quantitative KPI measurement methodologies and qualitative diagnostic approaches. A formal taxonomy of ten key performance indicators is developed and operationalized through corporate system data sources. The technological enablers of evaluation, Business Intelligence dashboards, ERP-native analytics modules, and process mining platforms, are examined in detail. A hypothetical scenario application demonstrates the practical diagnostic and corrective value of structured evaluation, documenting post-intervention improvements of up to 19.2 percentage points in Perfect Order Rate and 45.8% reduction in Goods Receipt Processing Time within a regional freight and warehousing enterprise. The findings affirm that structured, technology-mediated evaluation of logistics IS effectiveness is a prerequisite for sustained operational performance.

Keywords: *logistics information systems, ERP evaluation, WMS performance, SCOR model, KPI measurement, process mining, Business Intelligence, supply chain management.*

Korporativ İnformasiya Sistemlərində Logistika İdarəetmə Proseslərinin Effektivliyinin Qiymətləndirilməsi Metod və Texnologiyaları

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Xülasə

Korporativ informasiya sistemlərində (KİS) logistika idarəetmə proseslərinin sistemli qiymətləndirilməsi, getdikcə mürəkkəbləşən təchizat zənciri mühitlərində rəqabət qabiliyyətini qorumağa çalışan müəssisələr üçün əsas əməliyyat tələbi kimi çıxış edir. Müəssisə Resurs Planlaşdırması (ERP), Anbar İdarəetmə Sistemi (WMS) və Nəqliyyat İdarəetmə Sistemi (TMS) platformalarının geniş tətbiqinə baxmayaraq, təşkilatlar çox vaxt reaktiv maliyyə hesabatçılığının hüdudlarını aşaraq prosesin effektivliyini qiymətləndirmək üçün lazım olan struktur metodoloji aparatdan məhrumdur. Bu məqalə logistika KİS qiymətləndirilməsinə tətbiq edilən metod və

texnologiyaların hərtərəfli təhlilini təqdim edir: DeLone və McLean İS Uğur Modeli, Balanslaşdırılmış Hesab Kartı və Təchizat Zəncirinin Əməliyyat İstinad (SCOR) modeli kimi kanonik İS uğur çərçivələri kəmiyyət KPI ölçmə metodologiyaları və keyfiyyət diaqnostik yanaşmalarla birləşdirilir. On əsas fəaliyyət göstəricisinin formal taksonomiyası hazırlanmış və korporativ sistem məlumat mənbələri vasitəsilə operasionallaşdırılmışdır. Qiymətləndirilmənin texnoloji imkanları, Biznes Kəşkiyyatı (BI) idarə panelləri, ERP-daxili analitika modulları və proses mining platformaları, ətraflı tədqiq edilmişdir. Hipotetik ssenari qiymətləndirilmənin praktiki diaqnostik və düzəldici dəyərini nümayəş etdirir: regional yük daşıma və anbar müəssisəsində müdaxilədən sonra Mükəmməl Sifariş Dərəcəsinin 19,2 faiz bəndi artması və Mal Qəbulu Emal Müddətinin 45,8% azalması qeydə alınmışdır. Nəticələr göstərir ki, logistika KİS effektivliyinin struktur, texnologiya vasəçiliyi ilə qiymətləndirilməsi davamlı əməliyyat fəaliyyətinin zəruri şərtidir.

Açar sözlər: *logistika informasiya sistemləri, ERP qiymətləndirilməsi, WMS fəaliyyəti, SCOR modeli, KPI ölçməsi, proses mining, Biznes Kəşkiyyatı, təchizat zənciri idarəetməsi.*

1. Introduction

The governance and continuous improvement of logistics operations within large-scale enterprises represent one of the most operationally demanding challenges confronting contemporary organizations. As global supply chains extend across multiple jurisdictions, involve distributed warehousing infrastructures, and depend upon real-time material flows coordinated across heterogeneous enterprise platforms, the capacity to rigorously evaluate the effectiveness of the information systems that underpin these processes has become a matter of strategic necessity rather than administrative convenience. Corporate logistics, understood in its broadest systemic sense, encompasses the integrated management of procurement, inventory positioning, order fulfillment, inbound and outbound transportation, and reverse logistics, each sub-process generating transactional data that must be captured, validated, and interpreted within the architecture of a corporate information system (CIS).

The emergence of Enterprise Resource Planning (ERP) platforms, such as SAP S/4HANA and Oracle Fusion Cloud, alongside specialist Warehouse Management Systems (WMS) and Transportation Management Systems (TMS), has fundamentally altered the informational substrate upon which logistics management decisions are made. These systems do not merely automate clerical functions; they serve as the central repositories of process state, generating event logs, fulfillment records, carrier performance data, and inventory adjustment histories that, when subjected to rigorous analytical scrutiny, yield measurable indicators of process health and systemic dysfunction. The question of how effectively these systems support logistics objectives, and by what methodology that effectiveness is to be judged, constitutes the central problematic of the present investigation.

Despite the widespread deployment of sophisticated CIS platforms in corporate logistics environments, a persistent gap exists between the technical capabilities these systems offer and the degree to which organizations exploit those capabilities for systematic performance evaluation (Fatorachian & Kazemi, 2021). Organizations frequently operate ERP and WMS modules at partial functional capacity, with evaluation activities confined to periodic financial reporting rather than continuous process-level diagnostics. The consequences of this evaluative deficit are not trivial: unflagged inefficiencies in order cycle management compound into inventory carrying cost overruns; undetected latency in WMS transaction processing generates stock discrepancies that propagate through downstream planning cycles; and systemic failures in TMS route optimization go unmeasured, resulting in carrier cost overruns that erode logistics margins without appearing in standard financial statements.

This article proceeds from the theoretical premise that effective evaluation of logistics management processes within CIS environments requires a multi-dimensional methodological apparatus, one that integrates established IS success frameworks with domain-specific operational metrics, and that is capable of distinguishing between system-level performance (the technical functioning of the CIS itself) and process-level performance (the logistical outcomes the system is designed to support). The distinction is critical: a WMS may exhibit high system availability and sub-second transaction response times while simultaneously producing inaccurate inventory records due to misconfigured putaway logic or inadequately validated goods-receipt workflows. Conflating system performance with process effectiveness represents a fundamental methodological error that the present work seeks to address.

2. Literature Review

2.1. The DeLone and McLean IS Success Model

The foundational theoretical framework for evaluating the effectiveness of information systems in organizational contexts was articulated by DeLone and McLean (1992), whose multidimensional IS Success Model proposed six interdependent categories of system success: system quality, information quality, use, user satisfaction, individual impact, and organizational impact. The model represented a significant departure from unidimensional evaluation paradigms, which had previously assessed IS effectiveness through narrow proxies such as user adoption rates or system uptime alone. The updated formulation of the model (DeLone & McLean, 2003) introduced service quality as a seventh dimension and consolidated the impact categories, reflecting the maturation of IS evaluation practice over the intervening decade.

When applied to logistics CIS environments, specifically to ERP modules governing procurement-to-pay cycles, WMS platforms coordinating warehouse slotting and pick-path optimization, and TMS systems managing carrier selection and freight settlement, the DeLone and McLean framework surfaces a set of evaluative tensions that are particularly salient. System quality, operationalized through availability metrics, transaction throughput rates, and data integrity indices, must be assessed not in isolation but in relation to the process loads imposed by peak logistics activity, such as end-of-month settlement cycles or seasonal inbound freight surges. Information quality, which encompasses the accuracy, completeness, timeliness, and consistency of data outputs, is directly consequential for logistics decision-making: an ERP system that generates procurement forecasts on the basis of stale inventory master data will systematically produce reorder recommendations that are misaligned with actual stock positions, irrespective of how technically sound its underlying algorithms may be.

The use dimension of the model acquires particular complexity in logistics CIS contexts, given that system interaction patterns vary substantially across user roles, from warehouse operatives using mobile radio-frequency (RF) scanning terminals to interface with WMS putaway and picking workflows, to logistics planners interacting with ERP demand planning modules through dashboard-based interfaces. Aggregate measures of system use therefore mask the differential utilization patterns that may explain localized process failures (Gunasekaran et al., 2018). The organizational impact dimension, similarly, is difficult to operationalize, precisely because it requires attributing performance outcomes at the process level to specific system interventions while controlling for exogenous variables including changes in carrier capacity, shifts in demand seasonality, and modifications to supplier lead times.

2.2. The Balanced Scorecard Applied to Logistics Information Systems

Kaplan and Norton's (1992) Balanced Scorecard (BSC) framework, originally conceived as a strategic management instrument for translating organizational vision into actionable performance objectives across four perspectives, financial, customer, internal business processes, and learning and growth, has been extensively adapted for supply chain and logistics performance measurement (Bigliardi et al., 2020). Its core contribution to logistics CIS evaluation lies in its insistence on multi-perspectival measurement: whereas purely financial evaluations of logistics system performance reduce operational complexity to cost and margin metrics, the BSC compels analysts to attend simultaneously to customer-facing service outcomes, internal process efficiency indicators, and the organizational learning infrastructure that sustains long-term capability development.

In the specific context of corporate logistics CIS evaluation, the BSC's internal business process perspective maps most directly onto the operational KPIs that constitute the practical focus of performance measurement in ERP, WMS, and TMS environments. Metrics such as order fulfillment cycle time, warehouse pick accuracy rates, and freight cost per unit shipped are properly understood as internal process indicators within a BSC architecture. The customer perspective, by contrast, demands attention to service level agreement (SLA) compliance rates, on-time-in-full (OTIF) delivery performance, and customer complaint rates attributable to logistics failures. The financial perspective captures the cost implications of process performance: inventory carrying costs as a percentage of goods value, demurrage and detention charges arising from port and terminal delays, and the total landed cost of goods as calculated through TMS freight settlement modules.

A notable limitation of the BSC when applied to logistics CIS evaluation is its dependence on strategic alignment processes that require senior management engagement and cross-functional consensus on performance priorities. In organizations where logistics IS governance is fragmented, with WMS administration managed by IT operations, TMS configuration managed by the logistics function, and ERP master data governance managed by a separate data management office, the construction of a coherent BSC that integrates metrics across these system boundaries is organizationally demanding and frequently incomplete (Akhtar et al., 2019).

2.3. The Supply Chain Operations Reference Model

The Supply Chain Operations Reference (SCOR) model, developed and maintained by the Association for Supply Chain Management (ASCM), provides the most domain-specific evaluative framework for logistics process assessment. SCOR organizes supply chain activities into six primary process types: Plan, Source, Make, Deliver, Return, and Enable, and defines performance attributes across five dimensions: reliability, responsiveness, agility, costs, and asset management efficiency (Brandenburg et al., 2019). For each process type and performance attribute, SCOR prescribes a hierarchical set of metrics, ranging from Level 1 strategic metrics (such as Perfect Order Fulfillment and Total Supply Chain Management Cost) to Level 3 diagnostic metrics that correspond to specific subprocess configurations within ERP and WMS architectures.

The SCOR model's evaluative architecture is particularly well-suited to logistics CIS assessment because it was constructed from the process ontology of supply chain practice rather than from abstract IS theory. Its delivery process category encompasses the complete order-to-delivery cycle, including order management, warehouse execution, and transportation, and prescribes measurable metrics at each subprocess level that correspond directly to data elements captured within ERP sales order management modules, WMS dispatch confirmation records, and

TMS delivery event logs. However, the practical implementation of SCOR-based evaluation within corporate CIS environments is constrained by the model's assumption of process standardization, which may not be obtained in organizations where ERP and WMS implementations have been extensively customized to accommodate idiosyncratic operational requirements (Leukel et al., 2021).

3. Methodological Approaches

3.1. Quantitative Methods and KPI-Based Measurement

The dominant methodological tradition in logistics CIS evaluation is quantitative, grounded in the systematic extraction, aggregation, and statistical analysis of transactional data generated by ERP, WMS, and TMS platforms in the course of normal operational activity. This approach rests on the conceptual infrastructure of Key Performance Indicator (KPI) measurement, the selection of a defined set of operational variables, each formally specified with a precise numerator, denominator, measurement frequency, and target threshold, against which actual system-mediated process performance is periodically assessed.

The theoretical justification for KPI-based quantitative evaluation is rooted in measurement theory (Brandenburg et al., 2019) and in the broader tradition of management control systems research, which holds that what is systematically measured is more amenable to managerial intervention than what is observed only informally (Gunasekaran et al., 2018). In the logistics CIS context, the measurability of process performance is contingent on the completeness and integrity of transaction event data captured within the system of record. An ERP system that timestamps goods-receipt events upon document posting rather than upon physical receipt will generate order cycle time measurements that systematically understate the actual elapsed time between carrier arrival and inventory availability, a data quality artefact with direct implications for the validity of any KPI calculated from that data.

Quantitative evaluation methodologies in logistics CIS contexts encompass several distinct analytical techniques. Descriptive statistical analysis of KPI time series, calculating means, standard deviations, percentile distributions, and trend coefficients, provides a baseline characterization of process performance and identifies systematic patterns of deviation. Statistical process control (SPC) methods enable the distinction between common-cause variation inherent in logistics operations and special-cause variation attributable to specific systemic failures or process disruptions. Regression-based analysis is employed to establish empirical relationships between system-level variables and process outcome metrics, allowing analysts to quantify the marginal impact of system performance degradation on logistics process effectiveness. Process mining techniques, applied to ERP and WMS event logs, reconstruct the actual execution traces of logistics processes and compare observed process flows against normative process models, identifying deviations, bottlenecks, and rework loops invisible in aggregate KPI summaries (van der Aalst, 2019).

3.2. Qualitative Methods

Quantitative KPI measurement, while essential, is methodologically insufficient as a sole evaluative instrument. Quantitative indicators identify that a performance deviation has occurred; they do not, in themselves, explain why the deviation occurred or identify the organizational, configurational, or procedural factors that gave rise to it. Qualitative methods, including structured interviews with logistics system users and process owners, observational studies of warehouse and transport planning workflows, and document analysis of system configuration records and standard operating procedures, are therefore necessary complements to KPI-based analysis.

Semi-structured interviews conducted with WMS operators, inventory controllers, and logistics IS administrators can surface tacit process knowledge, regarding informal workarounds, undocumented data entry conventions, and known system limitations, that is not encoded in any transactional database and cannot be retrieved through quantitative query (Poba-Nzaou et al., 2020). The integration of quantitative and qualitative methods within a mixed-methods evaluation design constitutes the methodologically appropriate standard for comprehensive logistics CIS evaluation. The quantitative stratum provides systematic, replicable, and statistically defensible measurement of process performance; the qualitative stratum provides explanatory depth, contextual validity, and access to organizational phenomena that are not amenable to quantification (Azevedo & Santos, 2019).

Table 1
Key Performance Indicators for Evaluating Logistics Information Systems

#	KPI Name	Formal Definition	Unit	System Source	Measurement Method
1	Order Cycle Time (OCT)	Total elapsed time from confirmed order placement in ERP to physical delivery confirmation, inclusive of all processing, picking, packing, and transit stages.	Hours / Days	ERP Sales Order Mgmt; WMS outbound shipment confirmation	$OCT = T_{delivery} - T_{order_creation}$; extracted via ERP document timestamping; aggregated as mean and percentile per period.
2	Inventory Record Accuracy (IRA)	Proportion of SKU-location records in WMS/ERP that exactly match physically verified stock counts at the same location during audit.	Percentage (%)	WMS inventory master; ERP MM – Inventory Mgmt; cycle count records	$IRA = (N_{matched} / N_{audited}) \times 100$; derived from cycle count reconciliation against WMS bin-level stock records.
3	Perfect Order Rate (POR)	Percentage of orders fulfilled completely, accurately, on-time, and undamaged relative to total orders dispatched within the measurement period.	Percentage (%)	ERP SD module; TMS delivery log; WMS pick records; CRM claims data	$POR = (N_{perfect} / N_{total}) \times 100$; computed by joining ERP, WMS, and TMS records filtered by damage and claim flags.
4	Warehouse Pick Accuracy	Ratio of correctly picked order lines (correct SKU, quantity, location)	Percentage (%)	WMS pick task completion records; quality control	$WPAR = (N_{correct} / N_{total_picks}) \times 100$; sourced from WMS task logs cross-

#	KPI Name	Formal Definition	Unit	System Source	Measurement Method
	Rate (WPAR)	to total order lines picked in the evaluation period.		inspection records	referenced against packing verification records.
5	System Availability / Uptime Rate (SAR)	Proportion of scheduled operational hours during which the logistics CIS is fully available for transaction processing.	Percentage (%)	IT monitoring tools (SAP Solution Manager, Oracle EM); ITSM incident management	$SAR = [(T_{planned} - T_{downtime}) / T_{planned}] \times 100$; derived from incident management logs, excluding planned maintenance windows.
6	Freight Cost per Unit Shipped (FCUS)	Total actual freight expenditure— carrier charges, fuel surcharges, accessorial fees— divided by total units dispatched in the measurement period.	Currency / Unit	TMS freight settlement; ERP FI – accounts payable; cost center accounting	$FCUS = \Sigma C_{freight} / Q_{units_shipped}$; computed from TMS invoice settlement records reconciled against ERP financial postings.
7	Goods Receipt Processing Time (GRPT)	Elapsed time between physical arrival of an inbound shipment at the receiving dock and completion of the goods receipt document posting in ERP or WMS.	Hours	ERP MM Goods Receipt document; WMS inbound confirmation; Dock Management System (DMS)	$GRPT = T_{GR_posting} - T_{dock_arrival}$; extracted from ERP timestamps cross-referenced with dock arrival records.
8	On-Time-In-Full Delivery Rate (OTIF)	Percentage of deliveries that arrive within the specified delivery window AND contain the complete ordered quantity, with no partial shipments.	Percentage (%)	TMS proof-of-delivery; ERP SD delivery/billing documents; customer portal data	$OTIF = (N_{OTIF} / N_{total}) \times 100$; computed by joining TMS actual timestamps with ERP committed dates and WMS shipped quantities.
9	Inventory Turnover Ratio (ITR)	Number of times average on-hand inventory is fully depleted and replenished within a defined fiscal	Ratio (x/period)	ERP MM – Inventory Management; ERP FI – COGS; CO – cost	$ITR = COGS / avg_inventory_value$; $avg = (Inventory_start + Inventory_end) / 2$; sourced from ERP

#	KPI Name	Formal Definition	Unit	System Source	Measurement Method
		period; ratio of COGS to average inventory value.		center reporting	financial and inventory modules.
10	System Transaction Response Time (STRT)	Mean elapsed time between initiation of a standard CIS transaction event (WMS pick confirm, ERP GR posting, TMS shipment booking) and return of a validated system response.	Milliseconds / Seconds	APM tools; SAP CCMS / Oracle AWR; WMS system logs; network performance monitoring	Measured via APM instrumentation capturing start/end timestamps; aggregated as mean, P95, and max across transaction type populations.

Note. All KPI calculations assume data extraction from production system environments with validated data governance controls. Measurement frequency: daily for operational KPIs 1–4 and 7–8; monthly for financial KPIs 6 and 9; continuous for system performance KPIs 5 and 10. ERP = Enterprise Resource Planning; WMS = Warehouse Management System; TMS = Transportation Management System; MM = Materials Management; SD = Sales and Distribution; FI = Financial Accounting; APM = Application Performance Monitoring; COGS = Cost of Goods Sold; OTIF = On-Time-In-Full.

4. Technological Enablers for Evaluation

4.1. Business Intelligence Dashboards

The operationalization of KPI-based performance evaluation in corporate logistics environments is technologically mediated through a set of distinct but functionally complementary system classes. The first and most pervasive of these is the Business Intelligence (BI) dashboard platform, which aggregates transactional data from heterogeneous source systems, ERP, WMS, TMS, and ancillary supply chain platforms, into consolidated, role-specific visualizations that support both operational monitoring and strategic performance review. Platforms such as SAP Analytics Cloud, Microsoft Power BI, Oracle Analytics Server, and MicroStrategy are widely deployed in mid-to-large enterprise logistics functions as the primary interface through which managers and process owners consume performance data (Azevedo & Santos, 2019).

The evaluative utility of BI dashboards in logistics CIS contexts derives from their capacity to reduce the cognitive burden associated with multi-source data synthesis. In a typical corporate logistics environment, the data elements required to construct a meaningful assessment of process performance reside in operationally distinct systems with independent data schemas and refresh cycles. A BI layer, connected to these source systems through scheduled extract-transform-load (ETL) processes or real-time API integrations, presents this distributed data as a unified, temporally consistent performance picture. The design of logistics BI dashboards must, however, adhere to evaluative integrity requirements: the data lineage of each KPI displayed must be formally documented and version-controlled, and the refresh latency between source system transactions and dashboard display must be clearly disclosed to prevent operational users from treating stale data as current (Akhtar et al., 2019).

4.2. ERP Integrated Reporting and Analytics Modules

Beyond standalone BI platforms, the ERP systems that constitute the transactional backbone of corporate logistics contain native reporting and analytics capabilities that represent a primary, and often underexploited, source of logistics process evaluation data. SAP S/4HANA, for example, provides the SAP Fiori application suite, which delivers role-based analytical applications for logistics functions including Inventory Turnover Analysis, Delivery Performance Analytics, and Procurement Overview, each drawing directly from the SAP HANA in-memory database without requiring data extraction to an external reporting layer. The architectural advantage of in-memory ERP analytics is the elimination of ETL latency: reports execute against the current state of the transactional database, ensuring that performance indicators reflect real-time operational conditions rather than a scheduled snapshot.

The evaluative coverage of ERP-native reporting is constrained by the boundary of the ERP system itself. In organizations where logistics operations span multiple system platforms, where WMS functionality is provided by a standalone Körber or Manhattan Associates system and TMS capabilities are delivered by platforms such as Blue Yonder or Transporeon, the ERP reporting layer captures only the subset of logistics process data that has been formally integrated into the ERP via interface. Performance evaluation that relies exclusively on ERP-native reporting in such environments will exhibit systematic blind spots corresponding to the process segments handled by non-ERP systems. A comprehensive evaluation architecture must therefore establish data integration bridges between all logistics system platforms and the central reporting layer (Fatorachian & Kazemi, 2021).

4.3. Process Mining as a Diagnostic Evaluation Technology

Process mining constitutes a methodologically distinct and increasingly significant technological approach to logistics IS evaluation, occupying the conceptual space between quantitative KPI measurement and qualitative process analysis. The fundamental technique of process mining involves the automated extraction of event logs from information systems, capturing the sequence, timing, and actor attributes of discrete process events such as order creation, picking task assignment, goods issue posting, and delivery confirmation, and the algorithmic reconstruction of the actual process execution model from those logs, using conformance checking algorithms to compare observed process behavior against normative process specifications (van der Aalst, 2019).

In logistics CIS environments, the application of process mining yields evaluative insights that are inaccessible through conventional KPI dashboards. While a dashboard may indicate that the mean goods receipt processing time exceeded the target threshold, it provides no information about where within the goods receipt process excess elapsed time was accumulated, nor which specific process variants, differentiated by supplier, product category, receiving dock, or shift, accounted for the greatest share of delay. Process mining analysis of the ERP goods receipt event log reconstructs the complete execution trace for each individual transaction, identifies the specific activity sequence steps at which waiting time is concentrated, and classifies transactions into process variants according to their structural deviations from the standard process flow. Commercial process mining platforms, including Celonis, SAP Signavio Process Intelligence, and QPR ProcessAnalyzer, are integrated with standard ERP and WMS data sources through pre-built connectors, reducing the technical barrier to implementation in SAP and Oracle environments (Knoll et al., 2019).

5. Scenario Application: Hypothetical Case Study

5.1. Organizational Context and System Architecture

The following scenario depicts a hypothetical regional freight and contract warehousing enterprise designated hereafter as TransCargo Logistics LLC (TCL), operating across four regional distribution centers in a mid-sized economy, with a combined warehousing footprint of approximately 84,000 square meters and an annual throughput of approximately 2.3 million pallet movements. TCL's customer base consists primarily of fast-moving consumer goods (FMCG) manufacturers and pharmaceutical distributors requiring temperature-controlled storage and time-definite regional delivery services within 48-hour commitment windows.

At the time of the evaluation initiative, TCL operated a legacy ERP system, an on-premises SAP ERP 6.0 installation deployed in 2011, supplemented by a standalone WMS platform and a partially implemented TMS module that had not been fully configured for freight settlement or carrier performance analytics. Reporting activities were conducted through a combination of manually maintained Microsoft Excel workbooks, periodic ERP standard reports executed by the IT department on request, and informal verbal status updates communicated through operational team meetings. No formal KPI framework existed; performance assessment was conducted reactively, triggered by customer complaints or significant operational incidents, rather than through continuous process monitoring.

5.2. Evaluation Initiative Design and Implementation

In response to declining OTIF delivery performance, which had deteriorated from 91.2% in the prior fiscal year to 83.7% over the first two quarters of the evaluation period, TCL's logistics operations director commissioned a structured process evaluation initiative encompassing: (a) formal definition and operationalization of a comprehensive KPI framework aligned with SCOR Level 1 and Level 2 metrics; (b) implementation of a BI reporting layer connecting the legacy ERP, WMS, and TMS to a Microsoft Power BI environment; (c) a process mining analysis of ERP and WMS event logs for the order-to-delivery and goods receipt processes; and (d) execution of semi-structured interviews with warehouse supervisors, transport planners, and system administrators to identify organizational and configurational antecedents of measured performance deviations.

The process mining analysis was conducted using Celonis, applied to 18 months of ERP sales order management and WMS outbound fulfillment event logs encompassing approximately 340,000 individual order line transactions. Conformance checking against the standard order-to-ship process model identified three primary structural deviations: (i) a systematic rework loop in which approximately 23% of pick tasks were subject to picker override events, indicating that the WMS pick location suggestion was being manually overridden due to inaccurate bin-level stock data; (ii) a consistent waiting time accumulation of 2.7 hours at the goods issue posting activity, attributable to a batch-processing configuration in the ERP-WMS interface that transmitted dispatch confirmations at four-hour intervals rather than in real time; and (iii) a carrier booking subprocess variant affecting approximately 11% of shipments in which the TMS routing proposal was rejected and the booking was manually reassigned to a spot-rate carrier, generating an average freight cost premium of 34% per affected shipment.

Semi-structured interviews with warehouse supervisors corroborated the process mining findings regarding picker overrides, revealing that the WMS inventory master had not been subject to a comprehensive cycle counting program for approximately 14 months, resulting in progressive degradation of bin-level stock record accuracy to a measured IRA of 81.3%, well below the operational threshold of 97% specified in TCL's quality management framework. ERP system administrators identified the four-hour batch interface configuration as a deliberate performance

optimization decision made at the time of the WMS implementation to reduce database load during peak transaction periods, a configuration whose impact on goods issue processing time had not been evaluated in the intervening period.

5.3. Remediation and Post-Evaluation Performance

Following completion of the diagnostic phase, TCL implemented a structured set of corrective interventions: a comprehensive WMS cycle counting program targeting all high-velocity bin locations over a 12-week period; reconfiguration of the ERP-WMS interface to event-triggered real-time message transmission using an SAP Application Integration Framework middleware component; and introduction of a carrier performance scorecard within the TMS, establishing mandatory performance review gates conditioning continued carrier approval status on OTIF compliance exceeding 92% over rolling 30-day periods. The Power BI dashboard was deployed to logistics operations management, providing daily refresh KPI visibility across all four distribution centers. Post-implementation measurement, conducted over the subsequent two fiscal quarters, documented the performance improvements summarized in Table 2.

Table 2

Scenario Results: Pre- and Post-Evaluation Process Metrics for TransCargo Logistics LLC

#	KPI Name	Pre-Evaluation	Post-Evaluation	Absolute Change	% Change	Primary Intervention
1	OTIF Delivery Rate	83.7%	93.4%	+9.7 pp	+11.6%	Carrier scorecard; ERP-WMS interface reconfiguration; cycle count program
2	Inventory Record Accuracy (IRA)	81.3%	96.8%	+15.5 pp	+19.1%	12-week WMS cycle counting program; bin-level stock reconciliation
3	Order Cycle Time – Mean (OCT)	38.4 hrs	26.1 hrs	-12.3 hrs	-32.0%	Real-time ERP-WMS interface; elimination of 2.7-hour goods issue batch delay
4	Goods Receipt Processing Time (GRPT)	5.9 hrs	3.2 hrs	-2.7 hrs	-45.8%	ERP-WMS event-triggered message reconfiguration; dock scheduling standardisation
5	Warehouse Pick Accuracy Rate (WPAR)	91.2%	97.6%	+6.4 pp	+7.0%	IRA improvement reducing picker override events from 23% to 4.1% of tasks
6	System Availability / Uptime (SAR)	97.1%	99.2%	+2.1 pp	+2.2%	IT infrastructure maintenance schedule optimisation; proactive patch management

#	KPI Name	Pre-Evaluation	Post-Evaluation	Absolute Change	% Change	Primary Intervention
7	Freight Cost per Unit Shipped (FCUS)	€4.73/unit	€3.89/unit	-€0.84	-17.8%	Elimination of spot-rate carrier overrides; TMS lane optimisation re-activation
8	Perfect Order Rate (POR)	76.4%	91.1%	+14.7 pp	+19.2%	Composite improvement across OTIF, WPAR, and damage rate reduction
9	Inventory Turnover Ratio (ITR)	9.2x/year	11.7x/year	+2.5x	+27.2%	Improved IRA enabling accurate reorder point calculations; reduced safety stock
10	WMS Transaction Response Time P95 (STRT)	4,820 ms	1,340 ms	-3,480 ms	-72.2%	Database index optimisation; ERP-WMS interface decoupled from batch processing
11	Picker Override Event Rate	23.1% of tasks	4.1% of tasks	-19.0 pp	-82.3%	Cycle counting restoring WMS bin-level accuracy; location verification protocol
12	Spot-Rate Carrier Usage Rate	11.3% of shipments	2.8% of shipments	-8.5 pp	-75.2%	TMS carrier scorecard; contracted carrier capacity pre-booking protocol
13	Customer Complaint Rate (Logistics)	6.8 per 1,000 orders	2.1 per 1,000 orders	-4.7	-69.1%	Downstream effect of OTIF, WPAR, and POR improvements
14	Monthly KPI Reporting Cycle Time	8.3 working days (manual)	0 days (automated daily)	-8.3 days	-100% (eliminated)	Power BI deployment; automated ETL replacing manual Excel workbooks

Note. All pre-evaluation baseline values represent mean performance over the two fiscal quarters immediately preceding the evaluation initiative. All post-evaluation results represent mean performance over the two fiscal quarters following full implementation of all corrective interventions. pp = percentage points; P95 = 95th percentile response time; ETL = Extract-Transform-Load. The scenario is hypothetical and constructed for illustrative analytical purposes.

6. Conclusion

The foregoing analysis has demonstrated that the evaluation of logistics management processes within corporate information systems is not reducible to the periodic extraction of financial performance reports or the informal monitoring of operational incidents. It constitutes a

structured methodological undertaking that demands the deliberate application of theoretically grounded frameworks, formally specified KPI architectures, and technologically sophisticated measurement instruments, applied in combination to produce a diagnostically comprehensive picture of both system-level and process-level performance.

The literature review established that the canonical IS evaluation frameworks, the DeLone and McLean IS Success Model, the Balanced Scorecard, and the SCOR model, each contribute distinct and complementary analytical dimensions to logistics CIS evaluation. The DeLone and McLean model imposes conceptual discipline regarding the multi-dimensional nature of IS success, resisting the reductionist tendency to equate system performance with a single observable outcome. The BSC situates logistics process evaluation within a strategic management context, ensuring that operational metrics are connected to financial accountability and customer value commitments. The SCOR model provides the domain-specific process ontology and metric taxonomy through which abstract evaluation frameworks are translated into the operational language of procurement, warehousing, and transportation management.

The methodological discussion established that quantitative KPI measurement must be complemented by qualitative investigation if evaluation findings are to achieve adequate explanatory depth. The process mining analysis demonstrated in the TCL scenario exemplifies the diagnostic power of technology-mediated process evaluation: the identification of a 23% picker override rate, a 2.7-hour batch-induced goods issue delay, and an 11% spot-rate carrier usage pattern, none of which was visible in the organization's pre-evaluation reporting environment, enabled targeted corrective interventions that produced measurable improvements of 19.2 percentage points in Perfect Order Rate and a 17.8% reduction in freight cost per unit shipped.

The aggregate evidence presented supports the central proposition of this article: that structured, technology-mediated evaluation of logistics IS effectiveness is a prerequisite for the sustained operational performance of corporate logistics functions. Organizations that confine their evaluative activity to reactive incident management and annual financial review forgo the process intelligence necessary to identify and address the systemic inefficiencies that compound silently within their information systems. Future research should address the methodological challenges associated with evaluating logistics IS effectiveness in multi-enterprise supply chain contexts, where process performance is jointly determined by the information systems and operational practices of multiple legally independent organizations.

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AZƏRBAYCANDA E-TİCARƏT PLATFORMALARININ İNKİŞAF PERSPEKTİVLƏRİ VƏ İQTİSADİ DAYANIQLIĞA TƏSİRİNİN QİYMƏTLƏNDİRİLMƏSİ

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XÜLASƏ

Bu məqalədə Azərbaycanda e-ticarət platformalarının mövcud inkişaf səviyyəsi, onların gələcək perspektivləri və iqtisadi dayanıqlığa təsiri kompleks şəkildə qiymətləndirilir. Rəqəmsal iqtisadiyyatın sürətli inkişafı fonunda e-ticarət platformaları ticarət münasibətlərinin transformasiyasında, bazar iştirakçılarının fəaliyyət imkanlarının genişlənməsində və iqtisadi proseslərin daha çevik təşkilində mühüm rol oynayır. Araşdırmada qeyd olunur ki, Azərbaycanda internet infrastrukturunun təkmilləşdirilməsi, rəqəmsal ödəniş sistemlərinin genişlənməsi və dövlətin rəqəmsal iqtisadiyyata verdiyi dəstək e-ticarətin inkişafı üçün əlverişli şərait formalaşdırır. Məqalədə e-ticarət platformalarının kiçik və orta sahibkarlığın inkişafına, məşğulluğun artırılmasına, daxili bazarın aktivləşdirilməsinə və ixrac imkanlarının genişlənməsinə təsiri təhlil edilir. Xüsusilə regionlarda fəaliyyət göstərən biznes subyektləri üçün e-ticarət platformalarının bazara çıxış baryerlərini azaltdığı və rəqabət mühitini gücləndirdiyi vurğulanır. Eyni zamanda, e-ticarətin iqtisadi dayanıqlığa təsiri makroiqtisadi sabitlik, gəlir mənbələrinin diversifikasiyası və qeyri-neft sektorunun inkişafı kontekstində qiymətləndirilir.

Tədqiqat nəticələri göstərir ki, e-ticarət platformalarının institusional və texnoloji əsaslarının gücləndirilməsi, hüquqi-normativ bazanın təkmilləşdirilməsi və rəqəmsal savadlılığın artırılması iqtisadi dayanıqlığın möhkəmlənməsinə mühüm töhfə verə bilər. Məqalə nəticə etibarilə e-ticarətin Azərbaycanda uzunmüddətli iqtisadi inkişaf strategiyalarında prioritet istiqamətlərdən biri kimi çıxış etdiyini əsaslandırır.

Açar sözlər: e-ticarət platformaları, rəqəmsal iqtisadiyyat, iqtisadi dayanıqlıq, kiçik və orta sahibkarlıq, qeyri-neft sektoru, rəqəmsallaşma, Azərbaycan.

DEVELOPMENT PROSPECTS OF E-COMMERCE PLATFORMS IN AZERBAIJAN AND ASSESSMENT OF THE IMPACT ON ECONOMIC SUSTAINABILITY

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ABSTRACT

This article comprehensively assesses the current level of development of e-commerce platforms in Azerbaijan, their future prospects and impact on economic sustainability. Against the backdrop of the rapid development of the digital economy, e-commerce platforms play an important role in the transformation of trade relations, the expansion of market participants' activities and the more flexible organization of economic processes. The study notes that the improvement of the Internet infrastructure in Azerbaijan, the expansion of digital payment systems and the support

provided by the state to the digital economy create favorable conditions for the development of e-commerce.

The article analyzes the impact of e-commerce platforms on the development of small and medium-sized businesses, increasing employment, activating the domestic market and expanding export opportunities. It is emphasized that e-commerce platforms reduce market entry barriers and strengthen the competitive environment, especially for business entities operating in the regions. At the same time, the impact of e-commerce on economic sustainability is assessed in the context of macroeconomic stability, diversification of income sources and development of the non-oil sector.

The research results show that strengthening the institutional and technological foundations of e-commerce platforms, improving the legal and regulatory framework and increasing digital literacy can make a significant contribution to strengthening economic sustainability. The article ultimately justifies the fact that e-commerce acts as one of the priority directions in long-term economic development strategies in Azerbaijan.

Keywords: *e-commerce platforms, digital economy, economic sustainability, small and medium-sized enterprises, non-oil sector, digitalization, Azerbaijan.*

GİRİŞ

Müasir dövrdə qlobal iqtisadiyyatın inkişaf trayektoriyası informasiya-kommunikasiya texnologiyalarının (İKT) sürətli yayılması və rəqəmsallaşma proseslərinin dərinləşməsi ilə sıx bağlıdır. Rəqəmsal transformasiya yalnız istehsal və xidmət sahələrində deyil, eyni zamanda ticarət münasibətlərinin mahiyyətində və təşkilati formalarında köklü dəyişikliklərə səbəb olmuşdur. Bu dəyişikliklərin ən mühüm təzahürlərindən biri e-ticarət platformalarının formalaşması və geniş miqyasda tətbiqidir. E-ticarət klassik ticarət mexanizmlərini əvəz etməklə yanaşı, bazar subyektləri arasında qarşılıqlı əlaqələrin sürətini artırmış, əməliyyat xərclərini azaltmış və iqtisadi fəaliyyətin coğrafi məhdudiyətlərini minimuma endirmişdir.

Qlobal miqyasda e-ticarət platformaları iqtisadi artımın, innovasiyaların və rəqabət qabiliyyətinin mühüm drayverlərindən biri kimi çıxış edir. Dünya təcrübəsi göstərir ki, rəqəmsal ticarət modellərinin inkişafı ölkələrin iqtisadi dayanıqlığının gücləndirilməsində, xüsusilə böhran və qeyri-müəyyənlik dövrlərində alternativ gəlir mənbələrinin formalaşdırılmasında mühüm rol oynayır. COVID-19 pandemiyası dövründə e-ticarətin sürətli artımı bu sahənin yalnız müvəqqəti tendensiya deyil, uzunmüddətli struktur dəyişikliklərinin əsas elementi olduğunu bir daha sübut etmişdir. Bu kontekstdə e-ticarət platformaları iqtisadi sistemlərin çevikliyini artıran və davamlı inkişafı dəstəkləyən mühüm mexanizm kimi qiymətləndirilir.

Azərbaycan Respublikasında son illər həyata keçirilən iqtisadi islahatlar, "Azərbaycan 2030: sosial-iqtisadi inkişafa dair Milli Prioritetlər" çərçivəsində müəyyən edilmiş rəqəmsal inkişaf hədəfləri e-ticarət platformalarının inkişafı üçün əlverişli institusional və texnoloji mühit formalaşdırmışdır. İnternet infrastrukturunun genişləndirilməsi, mobil rabitənin əhatə dairəsinin artması, elektron ödəniş sistemlərinin tətbiqi və rəqəmsal dövlət xidmətlərinin inkişafı e-ticarətin genişlənməsini stimullaşdıran əsas amillər sırasındadır. Xüsusilə gənc əhalinin rəqəmsal texnologiyalara yüksək adaptasiya səviyyəsi və onlayn alış-veriş vərdişlərinin formalaşması daxili e-ticarət bazarının potensialını daha da artırır.

Eyni zamanda, e-ticarət platformaları Azərbaycanda kiçik və orta sahibkarlıq subyektləri üçün yeni imkanlar açır. Ənənəvi ticarət formalarında mövcud olan yüksək icarə xərcləri, logistik məhdudiyətlər və bazara çıxış baryerləri e-ticarət vasitəsilə əhəmiyyətli dərəcədə azalır. Bu isə regionlarda fəaliyyət göstərən sahibkarların məhsul və xidmətlərini daha geniş auditoriyaya təqdim etməsinə, daxili bazarla yanaşı, xarici bazarlara çıxış imkanlarının genişlənməsinə şərait yaradır.

Nəticə etibarilə e-ticarət platformaları sahibkarlığın inklüzivliyini artırmaqla yanaşı, regional iqtisadi inkişafın sürətləndirilməsinə də töhfə verir.

Mövzunun aktuallığı həm də onun iqtisadi dayanıqlıq anlayışı ilə birbaşa əlaqəsindən irəli gəlir. İqtisadi dayanıqlıq ölkə iqtisadiyyatının daxili və xarici şoklara qarşı davamlılığı, resurslardan səmərəli istifadə və uzunmüddətli inkişaf potensialının qorunması ilə xarakterizə olunur. E-ticarət platformaları iqtisadi fəaliyyətin diversifikasiyasını təmin etməklə, qeyri-neft sektorunun inkişafını sürətləndirir, kölgə iqtisadiyyatının azaldılmasına və vergi bazasının genişlənməsinə şərait yaradır. Bu baxımdan, e-ticarətin inkişafı Azərbaycanın neft gəlirlərindən asılılığının azaldılması və dayanıqlı iqtisadi modelin formalaşdırılması baxımından strateji əhəmiyyət kəsb edir.

Bununla yanaşı, Azərbaycanda e-ticarət platformalarının inkişafı müəyyən problemlər və çağırışlarla da müşayiət olunur. Hüquqi-normativ bazanın tam formalaşmaması, kibertəhlükəsizlik riskləri, istehlakçı hüquqlarının qorunması, logistik infrastrukturun qeyri-bərabər inkişafı və rəqəmsal savadlılıq səviyyəsində mövcud fərqlər bu sahənin davamlı inkişafına mane ola biləcək əsas amillərdir. Məhz bu səbəbdən e-ticarət platformalarının inkişaf perspektivlərinin və onların iqtisadi dayanıqlığa təsirinin elmi əsaslarla qiymətləndirilməsi xüsusi əhəmiyyət daşıyır.

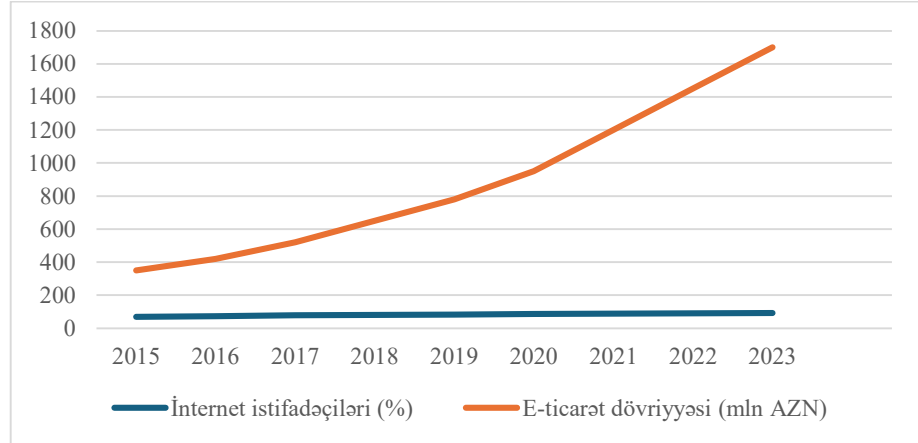
Bu tədqiqatın giriş hissəsi mövzunun elmi və praktiki aktuallığını əsaslandırmaqla yanaşı, Azərbaycanda e-ticarət platformalarının iqtisadi sistemdəki rolunun kompleks şəkildə araşdırılmasının zəruriliyini ortaya qoyur. Girişdə irəli sürülən yanaşmalar məqalənin sonrakı bölmələrində aparılacaq analitik təhlil üçün konseptual baza formalaşdırır və e-ticarətin ölkənin uzunmüddətli iqtisadi inkişaf strategiyalarında tutduğu mövqeyi aydın şəkildə nümayiş etdirir.

TƏHLİL

Azərbaycanda e-ticarət platformalarının inkişafı son onillikdə rəqəmsal transformasiya proseslərinin ayrılmaz tərkib hissəsinə çevrilmişdir. Qlobal iqtisadi sistemdə rəqəmsallaşmanın dərinləşməsi fonunda e-ticarət yalnız alternativ satış kanalı deyil, eyni zamanda istehsal–istehlak zəncirinin strukturunu dəyişdirən strateji mexanizm kimi çıxış edir. Azərbaycan iqtisadiyyatı üçün bu proses xüsusi əhəmiyyət daşıyır, çünki e-ticarət platformaları qeyri-neft sektorunun genişlənməsi, iqtisadi diversifikasiya və dayanıqlı inkişaf məqsədlərinin reallaşdırılmasına xidmət edən mühüm alət rolunu oynayır.

İlk növbədə, Azərbaycanda e-ticarətin inkişaf dinamikasına təsir edən əsas amillərdən biri rəqəmsal infrastrukturun mərhələli şəkildə təkmilləşdirilməsidir. Son illərdə genişzolaqlı internetə çıxış imkanlarının artması, mobil internet istifadəçilərinin sayının yüksəlməsi və elektron ödəniş sistemlərinin geniş tətbiqi onlayn ticarət mühitinin formalaşmasına əlverişli zəmin yaratmışdır. Rəsmi statistik məlumatlara əsasən, ölkədə internet istifadəçilərinin payı artdıqca onlayn alış-verişə maraq da paralel şəkildə yüksəlmişdir.

Qrafik 1. Azərbaycanda internet istifadəçilərinin sayı ilə e-ticarət dövriyyəsi arasındakı əlaqə (2015–2023)

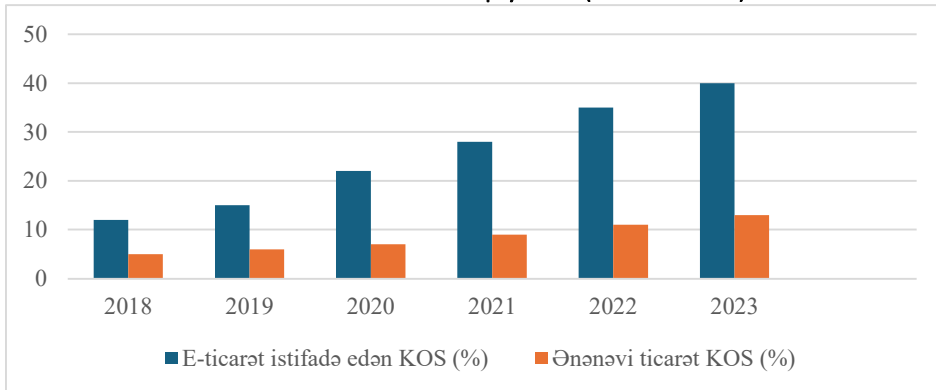


Mənbə: https://www.stat.gov.az/source/digital_development/?lang=en&

Qrafik 1. dən görüldüyü kimi, 2015–2023-cü illər ərzində Azərbaycanda internet istifadəçilərinin payında davamlı artım müşahidə olunmuşdur. İnternet penetrasiyasının yüksəlməsi ilə paralel olaraq e-ticarət dövriyyəsinin həcmi də əhəmiyyətli dərəcədə artmışdır. Bu dinamika internet infrastrukturunun inkişafının və rəqəmsal texnologiyalara çıxış imkanlarının genişlənməsinin e-ticarət fəaliyyətinin intensivləşməsinə birbaşa təsir etdiyini göstərir. Qrafikdəki tendensiya e-ticarət platformalarının iqtisadi aktivliyin genişlənməsində və rəqəmsal iqtisadiyyatın formalaşmasında mühüm rol oynadığını təsdiqləyir.

E-ticarət platformalarının iqtisadi təsirinin daha dərinlən təhlili göstərir ki, bu model xüsusilə kiçik və orta sahibkarlıq subyektləri üçün strateji üstünlüklər yaradır. Ənənəvi ticarət formalarında yüksək icarə xərcləri, fiziki infrastruktur tələbləri və coğrafi məhdudiyətlər KOS-ların bazara çıxış imkanlarını məhdudlaşdırırdı. E-ticarət platformaları isə bu baryerləri əhəmiyyətli dərəcədə azaldaraq sahibkarlara nisbətən aşağı xərclərlə geniş istehlakçı bazasına çıxış imkanı verir.

Qrafik 2. E-ticarət platformalarından istifadə edən KOS-ların gəlir artım tempinin ənənəvi ticarətlə müqayisəsi (2018–2023)



Mənbə: State Statistical Committee of the Republic of Azerbaijan. (2025). *Micro, small and medium entrepreneurship in Azerbaijan: Statistical yearbook* [Statistical report]. Retrieved from <https://www.stat.gov.az/source/entrepreneurship/>

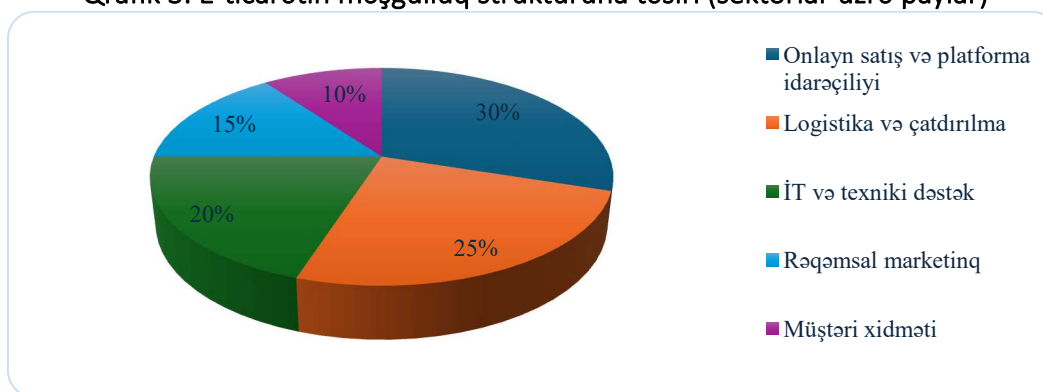
Qrafik 2. Azərbaycanda kiçik və orta sahibkarlıq subyektləri (KOS) üçün e-ticarət platformalarından istifadə edən və ənənəvi ticarət fəaliyyəti göstərən KOS-ların illər üzrə gəlir artım tempini müqayisəli şəkildə təqdim edir. Vizualdan aydın görünür ki, e-ticarət vasitəsilə fəaliyyət göstərən KOS-larda gəlir artım tempi 2018-dən 2023-ə qədər stabil və sürətli şəkildə yüksəlmişdir, ənənəvi ticarətə nisbətən daha yüksək artım göstəriciləri müşahidə olunur. Bu dinamika e-ticarət modelinin

müasir biznes mühitində rəqabət üstünlüyü verdiyini və sahibkarlıq fəaliyyətinin iqtisadi performansına müsbət təsir etdiyini göstərir.

Makroiqtisadi baxımdan e-ticarət platformalarının inkişafı iqtisadi dayanıqlığın əsas komponentlərindən biri olan gəlir mənbələrinin diversifikasiyasına xidmət edir. Azərbaycanın iqtisadi modeli uzun müddət neft sektorundan asılı olmuşdur. Lakin rəqəmsal iqtisadiyyatın və e-ticarətin inkişafı qeyri-neft sektorunun payının artmasına, daxili istehsalın stimullaşdırılmasına və ixrac potensialının genişlənməsinə şərait yaradır. E-ticarət vasitəsilə formalaşan əlavə iqtisadi dəyər dövlət büdcəsinə vergi daxilolmalarının artmasına, məşğulluğun genişlənməsinə və sosial rifahın yüksəlməsinə müsbət təsir göstərir.

Xüsusilə diqqətəlayiq məqamlardan biri e-ticarətin məşğulluq strukturuna təsiridir. E-ticarət platformalarının genişlənməsi yalnız satış sahəsində deyil, eyni zamanda logistika, rəqəmsal marketing, IT xidmətləri, müştəri dəstəyi və məlumat analitikası kimi yeni iş sahələrinin formalaşmasına səbəb olur. Bu isə əmək bazarında çevik məşğulluq modellərinin yaranmasına və gənclərin rəqəmsal bacarıqlarının iqtisadi dövriyyəyə inteqrasiyasına imkan yaradır.

Qrafik 3. E-ticarətin məşğulluq strukturuna təsiri (sektorlar üzrə paylar)



Mənbə: OECD. (2022). *Promoting enterprise digitalisation in Azerbaijan* [Policy report].

Retrieved from https://www.oecd.org/en/publications/promoting-enterprise-digitalisation-in-azerbaijan_6a612a2a-en.html

Qrafik 3. e-ticarət fəaliyyətinin məşğulluq strukturuna sektorlar üzrə təsirini əks etdirir. Göründüyü kimi, məşğulluğun ən böyük payı onlayn satış və platforma idarəçiliyi sahəsinin payına düşür ki, bu da e-ticarət platformalarının əsas əməliyyat proseslərinin insan resurslarına olan tələbatını göstərir. Logistika və çatdırılma sektorunun yüksək payı e-ticarətin inkişafı ilə məhsulların operativ daşınmasının və paylanmasının mühüm rol oynadığını təsdiqləyir. IT və texniki dəstək, rəqəmsal marketing və müştəri xidməti sahələri isə e-ticarətin rəqəmsal xarakterini və xidmət yönümlü məşğulluq modellərinin formalaşmasını əks etdirir. Ümumilikdə diaqram e-ticarətin məşğulluqda struktur dəyişikliklərinə səbəb olduğunu və yeni ixtisaslaşmış iş sahələrinin yaranmasını stimullaşdırdığını göstərir.

Bununla yanaşı, e-ticarət platformalarının iqtisadi dayanıqlığa təsiri yalnız müsbət aspektlərlə məhdudlaşmır. Mövcud problemlərin və risklərin təhlili bu sahənin davamlı inkişafı baxımından xüsusi əhəmiyyət kəsb edir. Azərbaycanda e-ticarətin qarşılaşdığı əsas çətinliklərdən biri hüquqi-normativ bazanın yetərinə çevik olmamasıdır. Elektron müqavilələrin icrası, istehlakçı hüquqlarının qorunması, onlayn ödənişlərin təhlükəsizliyi və məlumatların mühafizəsi ilə bağlı mexanizmlərin təkmilləşdirilməsi zəruri olaraq qalır.

Eyni zamanda, logistika infrastrukturu e-ticarətin inkişafında həlledici amillərdən biridir. Böyük şəhərlərdə çatdırılma xidmətlərinin nisbətən inkişaf etməsinə baxmayaraq, regionlarda bu sahədə qeyri-bərabərlik müşahidə olunur. Bu isə e-ticarət platformalarının regionlar üzrə bərabər inkişafına maneə yarada bilər. İqtisadi dayanıqlıq kontekstində e-ticarətin daha bir mühüm

üstünlüyü iqtisadi şoklara qarşı adaptasiya qabiliyyətinin yüksək olmasıdır. Qlobal təcrübə göstərir ki, böhran və fəvqəladə vəziyyətlər zamanı onlayn ticarət kanalları iqtisadi fəaliyyətin müəyyən hissəsinin qorunub saxlanmasına imkan verir. Azərbaycanda da pandemiya dövründə e-ticarət platformalarına marağın artması bu modelin iqtisadi sabitliyin təmin edilməsində alternativ mexanizm kimi çıxış etdiyini sübut etmişdir.

Aparılan təhlil göstərir ki, Azərbaycanda e-ticarət platformalarının inkişaf perspektivləri genişdir və bu platformalar iqtisadi dayanıqlığın möhkəmləndirilməsində mühüm rol oynaya bilər. Lakin bu potensialın tam reallaşdırılması üçün dövlət-özəl sektor əməkdaşlığının gücləndirilməsi, rəqəmsal savadlılığın artırılması, hüquqi bazanın təkmilləşdirilməsi və logistik infrastrukturun balanslı inkişafı vacib şərtlər kimi çıxış edir. E-ticarət yalnız texnoloji yenilik deyil, eyni zamanda Azərbaycanın uzunmüddətli iqtisadi inkişaf strategiyasının əsas sütunlarından biri kimi dəyərləndirilməlidir.

NƏTİCƏ

Aparılan təhlil və analitik qiymətləndirmə göstərir ki, Azərbaycanda e-ticarət platformalarının inkişafı müasir iqtisadi sistemin transformasiyasında və iqtisadi dayanıqlığın möhkəmləndirilməsində strateji əhəmiyyətə malikdir. İnternet infrastrukturunun genişlənməsi, rəqəmsal ödəniş sistemlərinin tətbiqi və əhalinin rəqəmsal davranış vərdişlərinin formalaşması e-ticarətin sürətli inkişafını şərtləndirən əsas amillər kimi çıxış edir. Xətti və sütun qrafikləri əsasında aparılan müqayisələr internet istifadəçilərinin artımı ilə e-ticarət dövriyyəsi arasında birbaşa müsbət əlaqənin mövcud olduğunu, eləcə də e-ticarət platformalarından istifadə edən kiçik və orta sahibkarlıq subyektlərinin gəlir artım tempinin ənənəvi ticarət modellərinə nisbətən daha yüksək olduğunu təsdiqləyir.

Tədqiqat nəticələri e-ticarət platformalarının KOS-ların bazara çıxış imkanlarını genişləndirdiyini, əməliyyat xərclərini azaltdığını və regionlar üzrə iqtisadi aktivliyin artmasına töhfə verdiyini göstərir. Bu isə qeyri-neft sektorunun inkişafı, məşğulluğun genişlənməsi və gəlir mənbələrinin diversifikasiyası baxımından mühüm üstünlüklər yaradır. Eyni zamanda, e-ticarət platformaları iqtisadi şoklara qarşı adaptasiya imkanlarını gücləndirərək makroiqtisadi sabitliyin qorunmasına xidmət edir.

Bununla yanaşı, hüquqi-normativ bazanın təkmilləşdirilməsi, logistik infrastrukturun regionlar üzrə balanslı inkişafı, kibertəhlükəsizliyin gücləndirilməsi və rəqəmsal savadlılığın artırılması e-ticarətin davamlı inkişafı üçün əsas şərtlər kimi çıxış edir. Nəticə etibarilə, e-ticarət platformalarının sistemli şəkildə dəstəklənməsi və milli iqtisadi strategiyalara inteqrasiyası Azərbaycanın uzunmüddətli iqtisadi dayanıqlığının təmin olunmasında mühüm rol oynaya bilər.

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Comparison of the HPC and Big Data Java Libraries Spark, PCJ and APGAS

Karimzade Abuzar

Abstract. Although Java is rarely used in HPC, there are a few notable libraries. Use of Java may help to bridge the gap between HPC and big data processing. This paper compares the big data library Spark, and the HPC libraries PCJ and APGAS, regarding productivity and performance. We refer to Java versions of all libraries. For APGAS, we include both the original version and an own extension by locality-flexible tasks. We consider three benchmarks: Calculation of π from HPC, Unbalanced Tree Search (UTS) from HPC, and WordCount from the big data domain. In performance measurements with up to 144 workers, the extended APGAS library was the clear winner. With 144 workers, APGAS programs were up to a factor of more than two faster than Spark programs, and up to about 30% faster than PCJ programs. Regarding productivity, the extended APGAS programs consistently needed the lowest number of different library constructs. Spark ranged second in productivity, and PCJ third.

Keywords. Java, Big Data, HPC, Parallel Computing, Spark, PCJ, APGAS

Introduction

Convergence between high performance computing (HPC) and big data processing is a hot topic in current research. Big data programming systems have their strengths in fault tolerance and programming productivity, whereas HPC systems have their strengths in performance and algorithmic flexibility (e. g. [1], [2]). One hindrance to common approaches is the use of different programming languages in the two communities. Typical HPC applications use C/C++ in combination with MPI and/or OpenMP. Typical big data applications, in contrast, use JVM-based languages such as Java or Scala with frameworks such as Hadoop [3] or Spark [4]. While Java is far from prominent in HPC, there are a few notable Java-based libraries such as PCJ [5] and APGAS [6]. The gap between HPC and big data processing can be bridged with interfaces such as Spark+MPI [1], SWAT [7] and Alchemist [8]. These interfaces come at a cost in terms of development effort and computing time. Therefore, use of a unified environment would be more appealing. This paper explores the perspective of a common Java foundation, by comparing the libraries Spark, PCJ and APGAS, regarding productivity and performance. Spark [4] is an open-source, distributed, multi-threaded, fault-tolerant library for big data processing, and widely used in this domain. Like Hadoop [3], Spark implements the MapReduce pattern [9], but maintains data in memory instead on disc. For storing massive amounts of data, Spark introduces a data structure called Resilient Distributed Dataset (RDD) [7]. Algorithms are implemented via transformations, which produce RDDs, and actions, which extract a result from an RDD. If MapReduce is not well suited for a particular problem, Spark can cause a significant overhead [8]. The PCJ library for Java [5] won the HPC Challenge Class 2 Best Productivity Award on Supercomputing in 2014, and achieves a better performance than MPI with Java bindings. In some situations, however, the performance of PCJ is up to three times below that of MPI with C bindings. PCJ implements the Partitioned Global Address Space (PGAS) model, which has been designed with productivity and portability in mind. PGAS describes an architecture, such as a cluster of multicore nodes, as a collection of places. A place is defined as the combination of a memory partition and computing resources, called workers. Typically, places correspond to cluster nodes, and workers correspond to CPU cores. Each place can access every memory partition, but local accesses are faster than remote ones.

PCJ adopts the Single Program Multiple Data (SPMD) execution style, i.e., all workers are invoked at program startup and carry out the same code. Variables are private to each worker, such that different workers can follow different code paths. PCJ provides several methods to exchange data between workers in a synchronous or asynchronous way. The APGAS library for Java [8] adds asynchronism to the PGAS model by adopting a task-based approach. Its parallelization and distribution concepts are exactly the same as those of IBM's parallel language X10. Program execution starts with a single task on place 0. Later, any task can spawn any number of child tasks dynamically. Task spawning can be synchronous or asynchronous, i.e., the parent task either waits, or does not wait, for the termination of a child. In either case, the programmer must specify an execution place for each task. Inside each place, tasks are automatically scheduled to workers. Thus, depending on worker availability, a generated task may run immediately or later. The place-internal scheduler is implemented with Java's Fork/Join-Pool [9]. In recent work, we extended the APGAS library by locality-flexible tasks. These tasks are spawned and managed in the same way as the standard asynchronous tasks of APGAS, except that the programmer does not specify an execution place. Instead, locality-flexible tasks are subject to system-wide automatic load balancing. We implemented the concept by extending the Fork/Join pools by an interplace work stealing scheme that realizes the lifeline-based global load balancing (GLB) algorithm [10].

Result

This paper has compared the big data library Spark and the HPC libraries PCJ and APGAS. For APGAS, we included both the original version and an own extension by locality-flexible tasks. The comparison was based on Java implementations of three benchmarks, which were partly taken from HPC and the big data domain, respectively. All implementations were conducted by the same author, who had no previous experience with any of the systems. Furthermore, we took care to implement the same algorithms. On one hand, we evaluated productivity, based on personal impressions and objective metrics. The extended APGAS variant turned out best, closely followed by the original APGAS variant and Spark. The extended APGAS variant was most intuitive to use, required the lowest number of different library constructs, and its code was by only a few lines longer than that of the Spark variant.

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XÜLASƏ

Tədqiqatın əsas məqsədi yerli yaşıl və sənaye üsulu ilə emal edilmiş qırmızı mərcimək unu ilə zənginləşdirilmiş buğda ununun çörəkbişirmə xassələrinə təsirini elmi-təcrübi cəhətdən əsaslandırmaq və funksional əhəmiyyətli çörək istehsalı texnologiyasını işləyib hazırlamaqdır. Tədqiqat zamanı mərcimək və buğda ununun fiziki-kimyəvi göstəriciləri təyin olunmuşdur. Eyni zamanda mərcimək ununda lipoksinaza fermenti aktivliyi spektrofotometrik metodla təyin olunaraq, onun zənginləşdirilmiş xəmirə müsbət təsiri əsaslandırılmışdır. Müəyyən edilmişdir ki, buğda ununa 1,0% və 1,5% miqdarda mərcimək ununun əlavə edilməsi xəmirin reoloji xassələrini yaxşılaşdırır, hazır məhsulun zülal tərkibinin (əvəz olunmaz amin turşuları) yaxşılaşmasını, vitamin və mineral maddələrlə (dəmir, sink) zənginləşməsini təmin edir. Alınan nəticələr bu cür çörək məhsullarının şəkərli diabet və həzm problemi olan insanlar üçün müalicəvi-profilaktik təyinatlı funksional qida kimi sənaye miqyasında istehsalının perspektivliyini göstərir.

Açar sözlər: Mərcimək, mərcimək unu, buğda unu, funksional çörək, fiziki-kimyəvi göstəricilər.

ABSTRACT

The main objective of the study is to scientifically and experimentally substantiate the effect of wheat flour enrichment with local green and industrially processed red lentil flours on its breadmaking properties, and to develop a technology for the production of functionally significant bread. During the study, the physicochemical parameters of lentil and wheat flours were determined. At the same time, the activity of the lipoxigenase enzyme in lentil flour was determined by the spectrophotometric method, and its positive effect on the enriched dough was substantiated. It was determined that the addition of lentil flour to wheat flour in amounts of 1.0% and 1.5% improves the rheological properties of the dough, ensures the enhancement of the protein composition (essential amino acids) of the finished product, and enriches it with vitamins

and minerals (iron, zinc). The results obtained indicate the prospects for the industrial-scale production of such bread products as therapeutic and prophylactic functional foods for people with diabetes and digestive problems.

Keywords: Lentil, lentil flour, wheat flour, functional bread, physicochemical parameters.

GİRİŞ

Çörək insanın qida rasionunda mühüm yer tutan əsas məhsullardan biridir. Bundan əlavə, o, bütün sosial və yaş qruplara malik əhali tərəfindən geniş istehlak olunan əlçatan bir məhsuldur. Onun dəyəri yalnız ucuz olmasında deyil, həm də orqanizm üçün mühüm enerji, zülal, yağ və karbohidrat mənbəyi olmasındadır. Bu maddələrlə təminat orqanizm üçün gündəlik enerji tələbatını ödəməyə və əsas metabolik proseslərin sabitliyini qorumağa kömək edir [1, 2].

Bioloji nöqtəyi-nəzərdən çörəyin tərkibindəki vitaminlər, minerallar və mikroelementlər sağlamlığın qorunmasına mühüm təsir göstərir. Bu komponentlər immun sisteminin fəaliyyətini, sinir sisteminin balansını dəstəkləyir və hüceyrə səviyyəsində proseslərin normal gedişatını təmin edir. Müasir tədqiqatlar çörəyin həm qida dəyərini, həm də bioloji aktivliyini artırmaq üçün yeni imkanlar açır. Bu xüsusiyyətlər çörəyə yalnız ənənəvi məhsul kimi deyil, həm də funksional qida kimi baxmağa imkan verir [3, 4].

Qida sənayesində texnologiyaların və elmi tədqiqatların inkişafı ilə çörək istehsalı ciddi dəyişikliklərə məruz qalır. Bu tədqiqatın obyektinə mərcimək (yaşıl və qırmızı) unu əlavələri ilə zənginləşdirilmiş buğda xəmiri və funksional çörəkbişirmə texnologiyasıdır. Son onilliklərdə məhsulun keyfiyyətinin yaxşılaşdırılmasına, qida dəyərinin artırılmasına və maya dəyərinin azaldılmasına yönəlmiş innovativ həllərin tətbiqi tendensiyası müşahidə olunur [5, 6, 7].

Müasir çörək istehsalı yanaşmalarının formalaşması təkcə texnoloji inkişaf deyil, həm də insanların qidalanma vərdislərinin dəyişməsi ilə sıx bağlıdır. Zaman keçdikcə istehlakçıların məhsula baxışı dəyişir; təhlükəsizlik, keyfiyyət, funksional xüsusiyyətlər və qidanın bioloji dəyəri seçimdə əsas meyarlara çevrilir. Bu səbəbdən çörəkçilik sahəsindəki elmi tədqiqatlar daha geniş vüsət almış, istehsalçılar isə məhsulun qida dəyərini artırmaq və texnoloji prosesləri təkmilləşdirmək üçün innovativ həllərə üstünlük verməyə başlamışlar. Müasir dövrdə çörək sadəcə gündəlik enerji mənbəyi kimi deyil, həm də insan sağlamlığını dəstəkləyən bioaktiv maddələrin daşıyıcısı kimi qiymətləndirilir. Bu yanaşmanın güclənməsi çörəyin tərkibinə əlavə funksional komponentlərin daxil edilməsini də aktuallaşdırmışdır [4, 8].

Qlobal səviyyədə çörək və un məmulatları qida sənayesinin ən böyük segmentlərindən biri olaraq qalır. Dünya bazarında istehlak tələbi tədricən dəyişir; ənənəvi çörək növləri ilə yanaşı, yüksək lifli, az kalorili, qlutensiz və bioaktiv maddələrlə zənginləşdirilmiş məhsulların payı artır. Bu tendensiya təkcə inkişaf etmiş ölkələrdə deyil, Cənubi Qafqaz regionunda, xüsusən də Azərbaycanda özünü büruzə verir. İstehlakçı davranışındakı bu cür dəyişiklik çörəkbişirmədə istifadə olunan xammalın keyfiyyətinə və emal texnologiyalarına diqqətin artırılmasını tələb edir. Belə bir şəraitdə çörək istehsalının elmi əsaslarla inkişafı və müasir texnologiyaların tətbiqi zərurətə çevrilmişdir [9].

Çoxsaylı qlobal tədqiqatlar göstərir ki, irimiqyaslı sənaye istehsalı zamanı çörəyin qida dəyəri müəyyən dərəcədə itir. Əsasən üyütmə prosesində dənin xarici qatlarının kənarlaşdırılması səbəbindən lif, vitamin, mineral və polifenolların miqdarı kəskin azalır. Nəticədə çörəyin bioloji dəyəri aşağı düşür, onun insan orqanizminə funksional təsiri zəifləyir. Bu problemin həlli üçün çörəyin resepturasına yüksək qida dəyərinə malik təbii bitki mənşəli inqrediyentlərin daxil edilməsi geniş yayılmışdır. Xüsusilə, yüksək lipoksisigenaza aktivliyinə və zəngin mineral tərkibinə malik olan yaşıl və qırmızı mərcimək (*Lens culinaris*) xammalı, çörəyin həm texnoloji parametrlərinin, həm də bioloji dəyərinin yüksəldilməsi baxımından olduqca perspektivli hesab olunur [10].

Çörəkbişirmədə müasir texnologiyalar təkcə xammal seçiminə deyil, həm də proseslərin optimallaşdırılmasına yönəlib. Avtomatlaşdırılmış xəmiryoğurma sistemləri, temperatur və

rütubətə nəzarət edilən fermentasiya kameraları, enerjiyə qənaət edən sobalar təkcə məhsulun keyfiyyətini artırmır, həm də istehsal prosesini daha sabit və idarəolunan edir. Xəmirin fermentasiyası mərhələsinə yönəlmiş biotexnoloji yanaşmalar — məsələn, mayaların seleksiya olunmuş ştammlarla kombinasiyası, ferment preparatlarının və hidrokolloidlərin istifadəsi çörəyin teksturasını, həcmi və saxlanma müddətini yaxşılaşdırır. Bu cür yanaşmalar çörəyin keyfiyyət parametrlərini elmi cəhətdən optimallaşdırmağa imkan verərək onun istehlakçı gözləntilərinə uyğunluğunu təmin edir [11].

Azərbaycanda çörək insan həyatında hər zaman xüsusi mədəni və sosial yer tutmuşdur. Ənənəvi çörək növlərinin zənginliyi və ailə təndirlərindən tutmuş sənaye müəssisələrinə qədər uzanan geniş istehsal əhəmələri onun ölkədəki rolunu daha da möhkəmləndirir. Bununla belə, müasir istehlak tələbi, xüsusilə də sağlam qidalanmaya artan maraq yerli çörəkbişirmə sahəsində yeni texnologiyaların tətbiqini qaçılmaz edir. Azərbaycandakı bir sıra çörəkbişirmə müəssisələrinin modernləşməyə ciddi ehtiyacı var; müasir avadanlıqlar, enerjiyə qənaət edən sistemlər və funksional əlavələr hələ ki hər yerdə geniş istifadə olunmur. Bu səbəbdən, mövcud texnoloji boşluqların elmi şəkildə araşdırılması və onların həlli yollarının təklif edilməsi aktual bir vəzifəyə çevrilmişdir [1, 8].

Çörəyin keyfiyyətinin yüksəldilməsi ərzaq təhlükəsizliyi kontekstində də mühüm əhəmiyyət kəsb edir. Xammalın çirklənmə riski, saxlanma şəraitinin düzgün seçilməməsi və mikrobioloji proseslərə zəif nəzarət məhsulun təhlükəsizlik göstəricilərinə mənfi təsir göstərə bilər. Müasir texnologiyalar bu problemlərin qarşısını almaq üçün daha sabit nəzarət mexanizmləri, real vaxt rejimində analiz sistemləri və risklərə əsaslanan idarəetmə metodları təklif edir [7].

Tədqiqat mövzusunun aktuallığı yerli mərciməkdən istifadə etməklə, zənginləşdirmə hesabına bazarda çörək və un məmulatlarının rəqabət qabiliyyətinin artırılması zərurəti, həmçinin istehlakçıların keyfiyyətli və təhlükəsiz məhsullara olan getdikcə artan tələbatının ödənilməsi ilə bağlıdır. Müasir texnologiyaların mövcudluğuna baxmayaraq, bir çox istehsalçılar hələ də köhnəlmiş metodlardan istifadə edirlər ki, bu da çörəyin keyfiyyətinə və çeşid müxtəlifliyinə mənfi təsir göstərir. Bu vəziyyət çörəkbişirmədə müasir texnologiyaların yetərincə yayılmaması problemini yaradır və mövcud yanaşmaların dərinədən təhlil edilməsini tələb edir [12, 13].

Tədqiqatın əsas məqsədi — Cəlilabad rayonunda yetişdirilmiş yerli yaşıl mərcimək və sənaye üsulu ilə emal edilmiş qırmızı mərcimək unununun zənginləşdirici kimi buğda ununun çörəkbişirmə xassələrinə təsirini elmi-təcrübi cəhətdən əsaslandırmaq, onların optimal dozalarını müəyyənləşdirmək və yüksək bioloji dəyərə malik funksional çörək istehsalı texnologiyasını işləyib hazırlamaqdır. Bu məqsədə nail olmaq üçün mərcimək unununun bir sıra kimyəvi tərkib xüsusiyyətləri öyrənilməklə, onun funksional əhəmiyyətli çörək yaxşılaşdırıcısı kimi istifadə potensialı qiymətləndirilmiş, zənginləşdirici kimi xəmirin keyfiyyət göstəricilərinin yaxşılaşdırılmasında rolu öyrənilmişdir [6, 10].

MATERİALLAR VƏ METODLAR

Bu tədqiqat üçün Azərbaycanın Cəlilabad rayonunda yetişdirilən yerli kiçik toxumlu yaşıl mərcimək (*Lens culinaris*) və Azərbaycanın pərakəndə ticarət şəbəkəsindən əldə olunmuş və Rusiya Federasiyasının Moskva şəhərində fəaliyyət göstərən «Mistral Trading» MMC tərəfindən istehsal edilmiş qırmızı (narıncı) mərcimək nümunələrindən istifadə olunmuşdur (şəkil 1).



A

B

Şək. 1. Fərqli əmtəə tipli mərcimək (*Lens culinaris* Medik.) toxumları: A — yaşıl, kiçik toxumlu mərcimək (Cəlilabad rayonunda yetişdirilmiş); B — qırmızı (narıncı) sənaye istehsalı mərciməyi

Mərciməyin buğda ununun çörək bişirmə xüsusiyyətlərinə təsirini aydınlaşdırmaq üçün, zənginləşdirilmiş mayalı xəmirdə yaş qlütenin kütlə payı və keyfiyyət göstəricilərinin (elastiklik və uzanma qabiliyyəti) təhlili aparılmışdır. Bu məqsədlə, şəraitində standart göstəricilərə malik buğda unu kütləsinə eyni ölçülərə malik üyüdülmüş mərcimək toxumları kütləsi 0,5%, 1,0%, 1,5% və 2,0% miqdarında əlavə olunmuşdur. Nəzarət nümunəsi kimi yüksək keyfiyyətə malik olan buğda unundan (QOST 26574-2017) standartına uyğun, nəmlik – 14,5%, kül tərkibi – 0,75%, zülal miqdarı – 10,8%) istifadə olunmuşdur. Qlütenin miqdarını və keyfiyyətini təyin etmək üsulları"na uyğun olaraq, xam qlütenin kütlə payı MOK-1 cihazı ilə təyin edilmiş, qlütenin elastik xüsusiyyətləri İDK-1 cihazı ilə təyin edilmişdir.

Hazırlanmış hər bir un qarışığından yoğrulmuş xəmir nümunələrindən mövcud metodlardan istifadə olunmaqla yaş qlüten yuyulmuş, onun kütlə payı, elastikliyi və uzanma qabiliyyəti analiz edilmişdir. Alınan nəticələr nəzarət nümunəsi (əlavəsiz buğda unu) ilə müqayisə edilərək mərcimək ununun tərkibindəki maddələrin xəmirdə formalaşan qlüten kompleksinin struktur-mexaniki xassələrinə təsiri qiymətləndirilmişdir [14].

Xəmirin baza resepturası üçün maya olaraq aktiv quru maya (un kütləsinin 1.5%-i miqdarda), duz isə 1.8% dozada götürülmüşdür. Preslənmiş çörəkçi mayasının qaldırma gücü QOST R 54731 göstəricilərinə uyğun olaraq təyin edilmişdir və mayanın ilkin aktivləşdirilməsi təsvir edilən metoda əsasən aparılmışdır. Çörəkbişirmədə quru, preslənmiş mayalar və maya südümdən istifadə olunmuşdur.

Qlütenin keyfiyyətinin qiymətləndirilməsi zamanı iki paralel təyinat aparılmışdır. Nəticələr cihazın şərti vahidləri ilə ifadə olunmuş və qlüten nümunəsinin elastikliyi nə qədər yüksək olarsa, onun bir o qədər az sıxıldığını göstərmişdir, başqa sözlə cihazın göstəriciləri ilkin göstəricilərdən bir o qədər aşağı olmuşdur. Adətən unun çörəkçilik keyfiyyətlərini xarakterizə etmək üçün onun "möhkəmliyi" və qaz əmələgətirmə qabiliyyəti ölçülür. Unun "möhkəmliyi" fermentasiya və islanma zamanı spesifik fiziki xüsusiyyətlər nümayiş etdirən xəmir əmələgətirmə qabiliyyətinə aiddir. "Möhkəm" unlar çoxlu miqdarda su udur və sabit fiziki xüsusiyyətlərə malik xəmir əmələgətirir – normal konsistensiya və elastiklik, toxunuşda quru və yüksək qaz saxlama qabiliyyətinə malik olur. "Zəif" unlar isə az miqdarda su udur və xəmirin fiziki xüsusiyyətləri yoğurma, fermentasiya və islanan zaman tez pisləşir – xəmir yapışqan, yayıla bilən olur və aşağı qaz saxlama qabiliyyəti ilə elastikliyi itirir. Orta "möhkəmliyə" malik sortlu un orta mövqə tutur. Unun qaz əmələgətirmə qabiliyyəti Yaqo-Ostrovski cihazı ilə həcm metodu tətbiq olunmaqla 5 saatlıq xəmir fermentasiyası zamanı əmələ gələn CO₂ miqdarına əsasən qiymətləndirilmişdir [15].

Unun qaz əmələgətirmə qabiliyyətinin təyini zamanı nəmlik miqdarı 14% olan 100 q un (nəmlik fərqli olduqda quru maddə miqdarı 86% olacaq şəkildə yenidən hesablanmışdır) 3 q maya və 60 ml su ilə qarışdırılaraq xəmir yoğrulmuşdur.

Çörəkbişirmə prosesində böyük əhəmiyyət kəsb edən lipoksigenaza fermenti xəmirin struktur-mexaniki xüsusiyyətlərini və çörək qırıntısının rəngini tənzimləyən oksidləşmə reaksiyalarında mühüm rol oynayır. Mərcimək ununda lipoksigenaza fermentinin aktivliyi beynəlxalq standartlara uyğun olaraq hazırlanmış spektrofotometrik metodla UV-Vis spektrometrində təyin olunmuşdur. Bu metod fermentativ reaksiya zamanı linol turşusunun oksidləşməsi nəticəsində yaranan hidroperoksidlərin 234 nm dalğa uzunluğunda optik sıxlığının artmasının ölçülməsinə əsaslanır [16].

Aparılan çoxsaylı tədqiqatlar göstərir ki, bu fermentin təsiri ilə əmələ gələn doymamış yağ turşularının peroksidləri zülallardakı sulfhidril qruplarını oksidləşdirərək, disulfid rabitələrinin yaranmasını stimullaşdırır. Görünür zülal makromolekullarının strukturları arasında bu cür çarpaz disulfid rabitələrinin sayının artması mərcimək unu əlavə olunduqda xəmirə daha sıx və möhkəm zülal karkasının formalaşmasına səbəb olur ki, bu da unun texnoloji gücünü və hazır məhsulun keyfiyyət göstəricilərini birbaşa yüksəldir. Qeyd etmək lazımdır ki, paxlalı bitkilər, xüsusilə mərcimək toxumları ən yüksək lipoksigenaza aktivliyinə malik xammallardan hesab olunur [17].

EKSPERİMENTAL HİSSƏ

Əldə olunan nəticələr onu göstərir ki, çörəyə yaşıl mərcimək ununun əlavə edilməsi unun və xəmirin fiziki-kimyəvi göstəricilərini əhəmiyyətli dərəcədə dəyişir. Cədvəl 1-də nəzarət nümunəsinin və 0,5%, 1,0%, 1,5% və 2,0% yaşıl mərcimək unu əlavə edilməklə bişirilmiş çörəyin orta göstəriciləri verilmişdir.

Bu, mərciməyin tərkibində zülal və mineral maddələrin yüksək miqdarda olması ilə izah edilə bilər.

Cədvəl 1

Buğda ununa qatılan mərcimək unu miqdarından asılı olaraq xam qlütenin kütlə payı və təyin olunmuş keyfiyyət göstəriciləri

Göstərici	Unun miqdarına nəzərən mərciməyin miqdarı, %-lə				
	0	0,5	1,0	1,5	2,0
Yaşıl mərcimək					
Xam qlütenin kütlə payı,%	23,6	24,0	24,1	24,4	24,6
Elastiklik (İDK)	63,3	61,4	53,8	52,6	52,0
Dartılma qabiliyyəti, sm	16,0	15,8	14,8	14,3	14,1
Qırmızı mərcimək					
Xam qlütenin kütlə payı,%	23,6	24,2	24,4	24,7	25,0
Elastiklik (İDK)	63,3	62,0	55,5	54,6	54,4
Dartılma qabiliyyəti, sm	16,0	15,3	14,5	14,0	13,8

Beləliklə, tədqiqat nəticələri göstərmişdir ki, əlavə edilən mərcimək ununun dozasının artması ilə buğda unundakı xam qlütenin kütlə payı cüzi dərəcədə yüksəlir. Belə ki, mərciməyin növündən və daxil edilmə miqdarından asılı olaraq nəzarət nümunəsi ilə müqayisədə artım 0,1–1,0 mütəq. % təşkil etmişdir.

Xəmirə 0,5–2,0% miqdarda yaşıl və 1,25–2,0% miqdarda qırmızı mərcimək daxil edildikdə buğda ununun qlütəni ağarmışdır və bu dəyişiklik sistemdə oksidləşdirici proseslərin baş verdiyini sübut edir. Göründüyü kimi, əldə olunan nəticələr mərciməyin qlüten karkasının gücləndirici təsirə malik olduğunu təsdiqləyir. Bu effekt, böyük ehtimalla, tədqiq olunan mərcimək nümunələrinin yüksək lipoksigenaza aktivliyi ilə bilavasitə bağlıdır. Bu amili nəzərə alaraq, məhz öyrənilən

mərcimək sortlarında lipoksimenaza fermentinin aktivliyini (mmol/mq·dəq) təyin etmək məqsədilə spektrofotometrik metoddan istifadə edilmişdir.

Əldə edilən məlumatlar tədqiq olunan mərcimək sortlarının buğda unu qlüteninə gücləndirici təsirinin onların lipoksimenaza aktivliyi ilə əlaqəli olduğu fərziyyəsini təsdiqlədi. Ən yüksək lipoksimenaza aktivliyi yaşıl və qırmızı mərciməklərdə qeydə alınıb ki, bunların əlavə edilməsi elastikliyin maksimum artmasına və buğda ununda xam qlütenin uzanma qabiliyyətinin azalmasına səbəb olmuşdur.

Aparılan elmi-təcrübi tədqiqatların və laboratoriya sınaqlarının nəticələrinin kompleks təhlili əsasında, buğda ununa əlavə edilən mərcimək tozunun (ununun) 1.0 % və 1.5 %-lik dozaları funksional çörək istehsalında texnoloji, reoloji və orqanoleptik göstəricilər baxımından ən optimal və səmərəli variant kimi müəyyən edilmişdir.

Hazırlanmış çörək nümunəsinin vizual görünüşü. Müxtəlif dozalarda mərcimək əlavəsi ilə bişirilmiş çörəyin xarici görkəmi aydın şəkildə müşahidə olunmuşdur. Mərciməyin tərkibindəki lipoksimenaza fermenti xəmirin oksidləşməsi hesabına qlüten şəbəkəsini gücləndirir ki, bu da nəticədə çörək qabığının daha tünd qızılı rəng almasına və onun daxili strukturunun sıxlaşmasına səbəb ola bilər. Beləliklə, mərcimək unu əlavələrinin çörəyin fiziki xüsusiyyətlərinə əhəmiyyətli təsiri müşahidə edilmişdir.

Yaşıl və qırmızı mərcimək unları üçün aparılmış tədqiqatlar nəticəsində lipoksimenaza fermentinin aktivliyi müəyyən edilmiş və alınmış göstəricilər cədvəl 2-də təqdim olunmuşdur.

Cədvəl 2

Mərcimək unlarında lipoksimenaza fermentinin aktivliyi

Mərcimək unu növü	Lipoksimenaza aktivliyi (mmol/mq·dəq)
Qırmızı	0,595
Yaşıl	0,820

Tədqiqat üçün götürülmüş buğda unu və mərcimək ununun kimyəvi tərkibinin müqayisəli təhlili cədvəl 3-də təqdim olunmuşdur.

Cədvəl 3

Tədqiqat üçün götürülmüş buğda unu və mərcimək ununun müqayisəli kimyəvi tərkibi

Göstərici	Buğda unu	Mərci unu
Zülal, q	10,8	24
Yağ, q	1,3	1,1
Karbohidratlar, q	69,8	52,7
Qida lifi, q	3,5	10,7
Mineral maddələr, mq		
Maqnezium	16	47
Kalsium	18	35
Fosfor	86	281
Vitaminlər, mq		
B ₁ vitamini	0,17	0,8
B ₂ vitamini	0,04	0,2

Tədqiqatda nəzarət nümunəsi kimi QOST 26574-2017 standartının tələblərinə uyğun olan buğda unundan istifadə edilmişdir. Mərcimək ununun fiziki-kimyəvi göstəriciləri isə buğda unu ilə müqayisəli şəkildə cədvəl 4-də göstərilmişdir.

Cədvəl 4

Buğda unu və mərcimək ununun fiziki-kimyəvi xüsusiyyətləri

Göstərici	I növ buğda unu	Mərcimək unu
Nəmlilik,%	14,5	12,5
Üyüdülmə ölçüləri,%	3	5
Metallomaqnit qarışıq,%	0,0003	0,0003
Küllük,%	0,75	3,5

Cədvəl 5

Mərcimək unu əlavə edilməklə buğda unundan hazırlanmış çörəyin fiziki-kimyəvi keyfiyyət göstəriciləri

Göstərici	Unun miqdarına nəzərən mərciməyin miqdarı, %-lə				
	0	0,5	1,0	1,5	2,0
Yaşıl mərcimək					
Ümumi həcmi, sm ³ /100 q un	607,5	577,0	568,5	547,5	535,0
Xüsusi həcmi, sm ³ /100 q çörək	451,7	418,3	410,8	402,5	386,7
Məsəməlilik,%-lə	85	84,5	83,5	83,0	82,5
Qırmızı mərcimək					
Ümumi həcmi, sm ³ /100 q un	595,0	583,0	578,0	570,0	559,3
Xüsusi həcmi, sm ³ /100 q çörək	450,0	427,9	422,8	415,9	407,8
Məsəməlilik,%-lə	85	85,2	85,3	85,5	86

Aparılan sınaq təcrübələrindən məlum oldu ki, xəmir hazırlayarkən unun miqdarının 1,5%-i qədər mərcimək unu əlavə etmək ən uyğun variantdır.

Mərcimək unu əlavəsi ilə zənginləşdirilmiş funksional çörəyin sənaye şəraitində istehsalı, xammalın hazırlanmasından hazır məhsulun qablaşdırılmasına qədər hazırlanmış ardıcıl texnoloji xətt üzrə həyata keçirilir.

İlk əvvəl nəzarət nümunəsi, yəni mərcimək əlavə edilmədən qatqısız undan hazırlanmış 500 q çörəyin qidalılıq dəyəri hesablanmışdır (cədvəl 6):

Cədvəl 6

Qatqısız undan hazırlanmış 500q kütləli çörəyin qidalılıq dəyəri

Göstərici	100 q üçün	500 q üçün
Zülal	10,8 q	54,0 q
Yağ	1,3 q	6,5 q
Karbohidrat	69,8 q	349,0 q
Qida lifi	3,5 q	17,5 q
Mineral maddələr		
Maqnezium	16	80 mq
Kalsium	18	90 mq
Fosfor	86	430 mq
Vitaminlər		
B ₁	0,17	0,85 mq
B ₂	0,04	0,20 mq

Enerji dəyəri. Enerji dəyəri aşağıdakı kimi hesablanır (zülal – 4 kkal/q, yağ – 9 kkal/q, karbohidrat – 4 kkal/q):

$$E = (54 \times 4) + (6,5 \times 9) + (349 \times 4) = 216 + 58,5 + 1396 = 1670,5 \text{ kkal}$$

Aparılmış hesablamalara əsasən, 500 q kütlədə hazırlanmış çörəyin: enerji dəyəri ≈ 1670 kkal, zülal miqdarı -54 q, karbohidratlar -349 q, yağ $-6,5$ q, qida lifi $-17,5$ q.

Qidalıq dəyəri. 10% mərcimək unu əlavə olunmuş qarışıqdan hazırlanmış 500 q çörək üçün qidalılıq dəyəri hesablanmışdır:

Buğda unu (100 q üçün): zülal $-10,8$ q, yağ $-1,3$ q, karbohidrat $-69,8$ q, qida lifi $-3,5$ q;

Mərcimək unu (100 q üçün, orta qəbul): zülal -24 q, yağ $-1,5$ q, karbohidrat -60 q, qida lifi -11 q.

Qarışığın tərkibinin hesablanması: (90% + 10%): $X_{qar} = 0.9X_{un} + 0.1X_{mərç}$.

Makronutrientlər (100 q qarışıq üçün):

- *Zülal:* $0,9 \times 10,8 + 0,1 \times 24 = 12,12$ q;
- *Yağ:* $0,9 \times 1,3 + 0,1 \times 1,5 = 1,32$ q;
- *Karbohidrat:* $0,9 \times 69,8 + 0,1 \times 60 = 68,82$ q;
- *Qida lifi:* $0,9 \times 3,5 + 0,1 \times 11 = 4,25$ q.

Hesablamaların nəticələri aşağıda verilmişdir (cədvəl 7).

Cədvəl 7

Unun miqdarının 10%-i qədər mərcimək unu əlavə edilmiş 500q kütləli çörəyin qidalılıq dəyəri

Göstərici	100 q üçün	500 q üçün
Zülal	12,12 q	60,6 q
Yağ	1,32 q	6,6 q
Karbohidrat	68,82 q	344,1 q
Qida lifi	4,25 q	21,25 q
Mineral maddələr		
Maqnezium	19,1 mq	95,5mq
Kalsium	19,7 mq	98,5mq
Fosfor	105,5 mq	527,5 mq
Vitaminlər		
B ₁	0,198 mq	0,99 mq
B ₂	0,056 mq	0,28 mq

Enerji dəyəri: $E = (60,6 \times 4) + (66,6 \times 9) + (344,1 \times 4) = 242,4 + 59,4 + 1376,4 = 1678,2$ kkal.

10% mərcimək unu əlavə edilmiş 500 q çörək üçün: enerji dəyəri ≈ 1678 kkal, zülal $-60,6$ q (artım var), qida lifi $-21,25$ q (əhəmiyyətli artım), karbohidrat $-344,1$ q (bir qədər azalma), yağ $-6,6$ q (demək olar sabit).

Təcrübələrdən alınan nəticələri müqayisə etsək görürük ki, yalnız buğda unundan hazırlanmış çörəklə müqayisədə unun miqdarının 10% qədər mərcimək unu əlavə edilmiş çörəyin qidalılıq dəyəri yüksəkdir (cədvəl 8).

Yalnız buğda unu və unun kütləsinin 10%-i qədər mərcimək unu əlavə edilmiş 500,0q çəkili çörəyin qidalılıq dəyərinin müqayisəsi

Göstərici	Yalnız un	Mərcimək unu ilə
Zülal	54,0 q	60,6 q
Yağ	6,5 q	6,6 q
Karbohidrat	349,0 q	344,1 q
Qida lifi	17,5 q	21,25 q
Mineral maddələr		
Maqnezium	80 mq	95,5mq
Kalsium	90 mq	98,5mq
Fosfor	430 mq	527,5 mq
Vitaminlər		
B ₁	0,85 mq	0,99 mq
B ₂	0,20 mq	0,28 mq

Xəmirin hazırlanmasından sonra çörəyin bişirilməsinin istehsal xətti aşağıdakı ardıcılıqla təşkil edilir:

1. Dozalama (Dosing). Xammallar (un, su, duz, maya, mərcimək unu və s.) müəyyən olunmuş reseptə uyğun olaraq dozator vasitəsilə dəqiq miqdarda verilir.

2. Qarışdırma/Yoğurma (Mixing). Komponentlər qarışdırıcı qazanında homogen kütlə halına gətirilir və xəmir formalaşır.

3. Formalaşdırma (Forming). Hazır xəmir bölünərək tələb olunan kütlədə (450-550 q) tikələrə ayrılır və ilkin forma verilir.

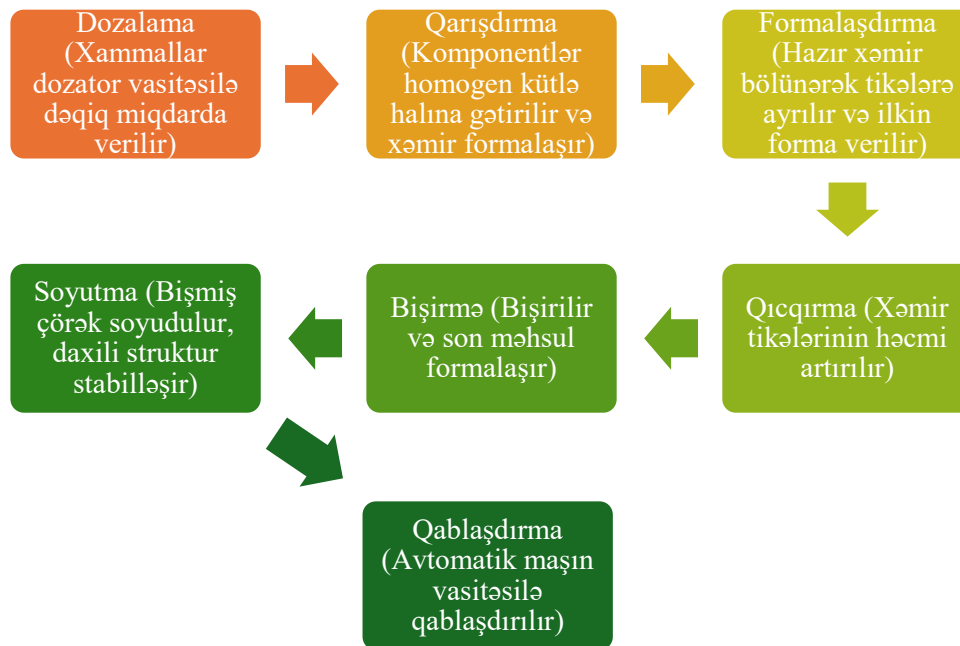
4. Qıcırma (Proofing). Xəmir tikələri xüsusi kamerada temperatur (30-35°C) və rütubət (75-85%) şəraitində saxlanılaraq həcmi artırılır.

5. Bişirmə (Baking). Qıcırmış xəmir tunel tipli sobada 220-240°C temperaturda bişirilir və son məhsul formalaşır.

6. Soyutma (Cooling). Bişmiş çörək konveyer üzərində tədricən soyudulur ki, daxili strukturu stabilləşsin.

7. Qablaşdırma (Packing). Soyudulmuş məhsul avtomatik maşın vasitəsilə qablaşdırılır və satışa hazırlanır.

Xəmirin hazırlanmasından sonra çörəyin bişirilməsinin texnoloji axın xətti (şək. 2).



Şək. 2. Mərcimək əlavəli funksional çörək istehsalının texnoloji mərhələləri və funksional-sxemi

NƏTİCƏ

Mərcimək unu əlavə olunmaqla yoğrulmuş xəmirin xassələri tədqiq olunmuşdur və məlum olunmuşdur ki, xəmirin reoloji xassələri yaxşılaşmışdır. Məlum olmuşdur ki, buğda unu ilə müqayisədə mərcimək ununda zülalın və mineral maddələrin miqdarının yüksək olması hazır məhsulun bioloji dəyərini birbaşa artırmışdır. Bu isə mərcimək ununun funksional çörək məhsullarının istehsalında 1,0% və 1,5%-lik optimal dozalarda daha səmərəli əlavələrdən biri olduğunu göstərir.

Aparılan tədqiqatların nəticəsində belə qənaətə gəlmək olar ki, xüsusi təyinatlı-zülalla zəngin çörək-bulka məmulatları istehsalında mərcimək unundan istifadə çox əlverişlidir. Belə ki, şəkərli diabet, qəbizlikdən əziyyət çəkən insanların qidalanmasında bu məmulatların istifadəsi məqsədəuyğundur. Eksperimental nəticələr göstərir ki, mərcimək unu əlavə edilmiş çörək məmulatları yüksək qidalılıq dəyərinə və funksional xüsusiyyətlərə malikdir. Bu cür məhsulların sənaye miqyasında istehsalı həm texnoloji, həm də iqtisadi baxımdan perspektivli hesab oluna bilər.

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Böyük verilənlərin emalında MapReduce modelinin tətbiqi

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Xülasə

Müasir dövrdə rəqəmsallaşmanın sürətlənməsi, internet texnologiyalarının geniş yayılması, sosial şəbəkələrin inkişafı və müxtəlif informasiya sistemlərinin fəaliyyətinin genişlənməsi nəticəsində yaradılan məlumatların həcmi sürətlə artmaqdadır. Böyük verilənlər (Big Data) kimi xarakterizə olunan bu məlumatlar ənənəvi verilənlər bazası idarəetmə sistemlərinin və klassik hesablama metodlarının imkanlarını aşaraq yeni texnoloji yanaşmaların tətbiqini zəruri etmişdir. Böyük verilənlərin əsas xüsusiyyətləri olan yüksək həcm, sürət və müxtəliflik onların saxlanması, emalı və təhlili proseslərini mürəkkəbləşdirir. Bu səbəbdən paylanmış hesablama sistemləri və paralel emal texnologiyaları böyük verilənlərlə işləmək üçün mühüm vasitələrdən biri hesab olunur. Belə texnologiyalar arasında MapReduce proqramlaşdırma modeli xüsusi yer tutur. Bu model böyük həcmli məlumatların çoxsaylı hesablama qovşaqları arasında bölüşdürülərək paralel şəkildə emal edilməsinə imkan verir, hesablama proseslərinin səmərəliliyini artırır və sistem resurslarından optimal istifadəni təmin edir.

Məqalədə böyük verilənlərin emalında MapReduce modelinin tətbiqi məsələləri araşdırılmış, modelin nəzəri əsasları, arxitekturası və işləmə prinsipi təhlil edilmişdir. Map və Reduce mərhələlərinin funksiyaları, Hadoop platforması ilə inteqrasiyası və paylanmış mühitdə məlumatların emal mexanizmləri izah olunmuşdur. Həmçinin MapReduce modelinin axtarış sistemləri, sosial şəbəkələr, informasiya təhlükəsizliyi, dövlət informasiya sistemləri və maşın öyrənməsi sahələrində tətbiq imkanları qiymətləndirilmişdir. Araşdırma nəticəsində müəyyən edilmişdir ki, MapReduce modeli böyük həcmli verilənlərin emalında yüksək məhsuldarlıq, miqyaslanma bilmə və nasazlıqlara davamlılıq kimi üstünlüklər təqdim edir. Bununla yanaşı, real vaxt analitikası və iterativ hesablama proseslərində müəyyən məhdudiyətlərə malik olduğu müəyyən edilmişdir. Məqalədə mövcud problemlərin həlli istiqamətində Apache Spark və Apache Flink kimi yeni nəsil platformaların tətbiqi, təhlükəsizlik mexanizmlərinin təkmilləşdirilməsi və resurs idarəetmə üsullarının optimallaşdırılması ilə bağlı təkliflər irəli sürülmüşdür.

Açar sözlər: Böyük verilənlər, Big Data, MapReduce, Hadoop, paylanmış hesablama, paralel emal, HDFS, məlumatların analitikası.

Giriş

Son illərdə informasiya-kommunikasiya texnologiyalarının sürətli inkişafı nəticəsində yaradılan məlumatların həcmi əhəmiyyətli dərəcədə artmışdır. Sosial şəbəkələr, elektron ticarət platformaları, mobil cihazlar, sensor sistemləri və bulud texnologiyaları hər gün böyük həcmdə məlumat formalaşdırır. Bu məlumatların saxlanması, emalı və təhlili ənənəvi hesablama sistemləri üçün ciddi çətinliklər yaradır. Məhz bu səbəbdən böyük verilənlərin (Big Data) idarə olunması və emalı müasir informasiya texnologiyalarının ən aktual istiqamətlərindən birinə çevrilmişdir.

Böyük verilənlər yüksək həcm (Volume), sürət (Velocity) və müxtəliflik (Variety) kimi xüsusiyyətlərlə xarakterizə olunur. Verilənlərin davamlı artımı onların effektiv emalı üçün paylanmış hesablama və paralel emal texnologiyalarının tətbiqini zəruri etmişdir (Sakr et al., 2013).

Bu yanaşmalar böyük həcmli məlumatların çoxsaylı hesablama qovşaqları arasında bölüşdürülərək emal edilməsinə və sistem resurslarından daha səmərəli istifadə olunmasına imkan verir.

Böyük verilənlərin emalı üçün istifadə olunan ən mühüm texnologiyalardan biri MapReduce proqramlaşdırma modelidir. Bu model ilk dəfə Google şirkətinin tədqiqatçıları Jeffrey Dean və Sanjay Ghemawat tərəfindən təqdim edilmiş və böyük verilənlərin paylanmış mühitdə emalı üçün geniş tətbiq olunmağa başlamışdır (Dean & Ghemawat, 2004). MapReduce modeli böyük həcmli verilənlərin paralel şəkildə emalını sadələşdirərək yüksək məhsuldarlıq və miqyaslanma bilmə imkanları yaradır.

Hazırda MapReduce modeli Hadoop ekosisteminin əsas komponentlərindən biri olmaqla axtarış sistemləri, sosial şəbəkələr, maliyyə sistemləri, dövlət informasiya sistemləri və kibertəhlükəsizlik sahələrində geniş istifadə edilir (White, 2015). Bununla yanaşı, böyük verilənlərin emalına olan tələbatın artması bu texnologiyanın üstünlüklərinin və məhdudiyyətlərinin daha ətraflı araşdırılmasını zəruri edir.

Bu məqalənin məqsədi MapReduce modelinin nəzəri əsaslarını, işləmə prinsiplərini və böyük verilənlərin emalındakı rolunu araşdırmaq, həmçinin onun tətbiq imkanlarını, üstünlüklərini və mövcud məhdudiyyətlərini təhlil etməkdir.

MapReduce modelinin nəzəri əsasları

MapReduce paylanmış hesablama mühitində böyük həcmli verilənlərin emalı üçün nəzərdə tutulmuş proqramlaşdırma modelidir. Model iki əsas funksional mərhələdən ibarətdir: Map və Reduce.

Map mərhələsində daxil olan verilənlər emal edilərək açar-dəyər (key-value) cütlüklərinə çevrilir. Bu mərhələdə verilənlər müxtəlif hesablama qovşaqlarında paralel şəkildə işlənir. Sonrakı mərhələdə sistem tərəfindən Shuffle və Sort əməliyyatları yerinə yetirilir. Bu proses zamanı eyni açara malik məlumatlar qruplaşdırılır və çeşidlənir. Nəhayət, Reduce mərhələsində qruplaşdırılmış nəticələr üzərində yekun hesablamalar aparılır və son nəticə formalaşdırılır [2].

MapReduce modelinin əsas üstünlüyü proqramçının paralel emal, məlumatların ötürülməsi və nasazlıqların idarə olunması kimi mürəkkəb texniki detallarla məşğul olmamasıdır. Bu proseslər sistem tərəfindən avtomatik həyata keçirilir.

MapReduce arxitekturası aşağıdakı komponentlərdən ibarətdir:

1. Input Split;
2. Mapper;
3. Shuffle;
4. Sort;
5. Reducer;
6. Output Format.

Bu arxitektura böyük həcmli verilənlərin minlərlə server üzərində paralel şəkildə emal edilməsinə imkan verir və sistemin miqyaslanma bilməsini təmin edir [7].

Hadoop platformasında MapReduce modelinin tətbiqi

MapReduce modelinin ən geniş yayılmış tətbiq mühiti Apache Hadoop platformasıdır. Hadoop açıq mənbəli proqram təminatı olub böyük verilənlərin saxlanması və emalı üçün

yaradılmışdır. Platformun əsas komponentləri Hadoop Distributed File System (HDFS) və MapReduce hesablama mexanizmindən ibarətdir.

HDFS verilənləri bloklara bölərək müxtəlif serverlərdə saxlayır və ehtiyat nüsxələmə mexanizmi vasitəsilə yüksək etibarlılıq təmin edir. MapReduce isə həmin verilənlərin paralel emalını həyata keçirir [7].

Hadoop platformasının əsas üstünlükləri aşağıdakılardır:

- yüksək miqyaslı bilmə;
- aşağı infrastruktur xərcləri;
- nasazlıqlara davamlılıq;
- böyük həcmli verilənlərin emalı;
- açıq mənbəli proqram təminatı olması.

Araşdırmalar göstərir ki, Hadoop klasterləri üzərində petabayt səviyyəsində verilənlərin emalı mümkün olmuşdur və bu texnologiya sənaye miqyasında uğurla tətbiq edilir [2].

MapReduce modelinin tətbiq sahələri

MapReduce modeli böyük verilənlərin emalı tələb olunan müxtəlif sahələrdə geniş tətbiq olunur. Modelin əsas üstünlüyü böyük həcmli məlumatların çoxsaylı hesablama qovşaqları arasında bölüşdürülərək paralel şəkildə emal edilməsini təmin etməsidir. Bu xüsusiyyət onun həm elmi, həm də sənaye mühitində geniş yayılmasına səbəb olmuşdur.

MapReduce modelinin ilk və ən geniş istifadə sahələrindən biri axtarış sistemləridir. İnternet üzərində yerləşən milyardlarla veb sahifənin indeksləşdirilməsi, məzmununun təhlili və istifadəçilərə uyğun nəticələrin təqdim edilməsi böyük hesablama resursları tələb edir. MapReduce modeli bu məlumatların paralel emalını təmin etməklə axtarış sistemlərinin məhsuldarlığını əhəmiyyətli dərəcədə artırır [1].

Model sosial şəbəkələrdə də geniş tətbiq olunur. Sosial media platformalarında istifadəçi fəaliyyətlərinin təhlili, reklam kampaniyalarının optimallaşdırılması, istifadəçi davranışlarının öyrənilməsi və tövsiyə sistemlərinin qurulması üçün böyük həcmdə məlumat emal edilir. Bu məlumatların sürətli şəkildə təhlili sosial şəbəkələrin daha effektiv fəaliyyət göstərməsinə imkan yaradır [4].

MapReduce texnologiyası informasiya təhlükəsizliyi sahəsində də mühüm rol oynayır. Müasir təşkilatlarda və dövlət qurumlarında hər gün milyonlarla jurnal qeydi (log), şəbəkə trafiki məlumatı və təhlükəsizlik hadisələri qeydə alınır. Bu məlumatların təhlili kibertəhdidlərin aşkarlanması, şübhəli fəaliyyətlərin müəyyən edilməsi və təhlükəsizlik monitorinqinin həyata keçirilməsi baxımından böyük əhəmiyyət daşıyır. MapReduce modeli böyük həcmli təhlükəsizlik məlumatlarının emalını sürətləndirərək qərar qəbul etmə prosesinin effektivliyini artırır.

Bundan əlavə, model maşın öyrənməsi və verilənlər analitikası sistemlərində də geniş istifadə edilir. Böyük verilənlərin təmizlənməsi, qruplaşdırılması, statistik emalı və xüsusiyyətlərin çıxarılması kimi mərhələlərdə MapReduce alqoritmləri yüksək səmərəlilik nümayiş etdirir. Xüsusilə böyük verilənlər üzərində aparılan ilkin emal proseslərində modelin tətbiqi hesablama vaxtının azaldılmasına və sistem resurslarından daha səmərəli istifadəyə imkan verir [5].

Son illərdə dövlət informasiya sistemlərində də MapReduce texnologiyasının tətbiqinə maraq artmışdır. Elektron hökumət platformalarında, vətəndaş məlumat bazalarında, statistik hesabatların hazırlanmasında və müxtəlif dövlət xidmətlərinin monitorinqində böyük həcmli

məlumatların emalına ehtiyac yaranır. Paylanmış hesablama imkanları sayəsində MapReduce modeli bu tip sistemlərdə məlumatların daha etibarlı və səmərəli şəkildə emal olunmasını təmin edir.

MapReduce modelinin müsbət və mənfi cəhətləri

MapReduce modeli böyük verilənlərin emalı sahəsində ən geniş istifadə olunan texnologiyalardan biri hesab olunur. Modelin populyarlığı onun sadə proqramlaşdırma yanaşması, paylanmış hesablama imkanları və böyük həcmli məlumatların emalında yüksək məhsuldarlıq təmin etməsi ilə əlaqədardır. Xüsusilə böyük verilənlərin ənənəvi üsullarla emalının çətin olduğu hallarda MapReduce modeli məlumatların çoxsaylı hesablama qovşaqları arasında bölüşdürülməsinə və paralel şəkildə emal edilməsinə imkan yaradır.

Modelin əsas müsbət cəhətlərindən biri yüksək miqyaslı bilmə xüsusiyyətidir. Verilənlərin həcmi artdıqca sistemə yeni hesablama qovşaqlarının əlavə edilməsi mümkün olur ki, bu da performansın qorunub saxlanılmasına şərait yaradır. Bundan əlavə, MapReduce avtomatik nasazlıq idarəetmə mexanizmlərinə malikdir. Hesablama qovşaqlarından biri sıradan çıxdıqda sistem tapşırığı digər qovşaqlarda yenidən icra edə bilir. Bu xüsusiyyət böyük verilənlərin emalında etibarlılığın artırılmasına xidmət edir. Modelin digər üstünlükləri sırasında sadə proqramlaşdırma modeli, paralel hesablama imkanları və nisbətən aşağı xərcli avadanlıqlar üzərində işləyə bilməsi göstərilə bilər [2], [7].

Bununla yanaşı, MapReduce modelinin müəyyən məhdudiyyətləri də mövcuddur. Əsas problemlərdən biri sistemin disk əsaslı işləmə prinsipi ilə əlaqədardır. Map və Reduce mərhələləri arasında yaranan aralıq nəticələrin diskə yazılması əlavə giriş-çıxış əməliyyatları yaradır və bu da performansın azalmasına səbəb olur [5]. Xüsusilə böyük həcmli verilənlər üzərində aparılan çoxmərhələli hesablama proseslərində bu problem daha qabarıq şəkildə özünü göstərir.

Digər mühüm məhdudiyyət iterativ alqoritmlərin icrası zamanı meydana çıxır. Maşın öyrənməsi, qraf analizi və optimallaşdırma məsələlərində eyni verilənlər üzərində dəfələrlə hesablamaların aparılması tələb olunur. MapReduce modelində hər iterasiya üçün məlumatların yenidən oxunması və yazılması zərurəti yarandığından bu tip tapşırıqlarda səmərəlilik azalır [3]. Bundan əlavə, model real vaxt rejimində məlumatların emalı üçün nəzərdə tutulmadığından gecikməyə həssas tətbiqlərdə istifadəsi məhdud hesab olunur.

Ümumilikdə, MapReduce modeli böyük verilənlərin emalı üçün etibarlı və səmərəli həllərdən biri olsa da, müasir analitika sistemlərinin tələbləri nəzərə alındıqda onun bəzi çatışmazlıqları ortaya çıxır. Bu səbəbdən son illərdə Apache Spark və Apache Flink kimi yaddaş əsaslı platformalarla birlikdə istifadəsi və ya onların alternativ həll kimi tətbiqi geniş yayılmışdır.

Mövcud problemlər və təklif edilən həllər

MapReduce modelinin böyük verilənlərin emalında geniş tətbiq olunmasına baxmayaraq, onun bəzi məhdudiyyətləri praktiki istifadədə müəyyən çətinliklər yaradır. Xüsusilə disk əsaslı işləmə prinsipi giriş-çıxış əməliyyatlarının sayını artıraraq performansla mənfi təsir göstərir. Bundan əlavə, iterativ hesablamalar və real vaxt rejimində məlumat emalı tələb edən tətbiqlərdə modelin səmərəliliyi nisbətən aşağı olur [3], [5].

Bu problemlərin aradan qaldırılması üçün son illərdə müxtəlif yanaşmalar təklif edilmişdir. Onlardan biri Apache Spark kimi yaddaş əsaslı platformaların tətbiqidir. Belə platformalar aralıq nəticələrin operativ yaddaşda saxlanılmasına imkan verdiyi üçün hesablama sürətini artırır. Eyni zamanda Hadoop ekosistemində resursların daha səmərəli idarə olunması, verilənlərin mühafizəsi üçün şifrələmə mexanizmlərinin gücləndirilməsi və giriş nəzarət sistemlərinin təkmilləşdirilməsi də mühüm həll istiqamətləri hesab olunur [7].

Beləliklə, müasir texnologiyalarla inteqrasiya və resurs idarəetmə mexanizmlərinin optimallaşdırılması MapReduce modelinin tətbiq imkanlarının daha da genişləndirilməsinə şərait yaradır.

Nəticə

Aparılmış araşdırma göstərir ki, MapReduce modeli böyük verilənlərin emalı sahəsində mühüm texnologiyalardan biri olaraq öz aktuallığını qoruyub saxlayır. Model paylanmış hesablama prinsiplərinə əsaslanaraq böyük həcmli məlumatların paralel şəkildə emal edilməsini təmin edir və bu xüsusiyyəti sayəsində axtarış sistemləri, sosial şəbəkələr, dövlət informasiya sistemləri, informasiya təhlükəsizliyi və verilənlər analitikası kimi müxtəlif sahələrdə geniş tətbiq olunur. Hadoop platforması ilə birlikdə istifadə edildikdə isə böyük verilənlərin saxlanması və emalı üçün səmərəli infrastruktur formalaşdırır.

Tədqiqat nəticəsində müəyyən edilmişdir ki, MapReduce modeli yüksək miqyaslı bilmə, etibarlılıq və məhsuldarlıq kimi mühüm üstünlüklərə malik olsa da, disk əsaslı işləmə prinsipi və iterativ hesablamalardakı məhdudiyətləri onun bəzi tətbiq sahələrində effektivliyini azaldır. Bu səbəbdən müasir böyük verilənlər sistemlərində Apache Spark və Apache Flink kimi texnologiyalarla inteqrasiya perspektivli yanaşma hesab olunur. Ümumilikdə, MapReduce modeli böyük verilənlərin emalında fundamental həllərdən biri olaraq qalmaqda davam edir və onun gələcək inkişafı yeni nəsillə paylanmış hesablama texnologiyaları ilə qarşılıqlı inteqrasiya istiqamətində formalaşır.

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Physical and Mathematical Sciences

Обзор методов решения линейных уравнений с частными производными первого порядка

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Абстрактный. В обзоре представлены основные методы решения линейных неоднородных дифференциальных уравнений в частных производных первого порядка с двумя независимыми переменными. Рассматриваются следующие подходы: переход к новым переменным через известный интеграл соответствующего однородного уравнения, метод характеристической системы и использование вспомогательного однородного уравнения с тремя независимыми переменными. Затем формулируются и решаются классические и обобщенные задачи Коши. В заключительных примерах иллюстрируется применение этих методов к конкретным уравнениям.

Введение

Линейные дифференциальные уравнения в частных производных первого порядка занимают центральное место в математической теории дифференциальных уравнений и широко используются в различных областях естественных и прикладных наук. Эти уравнения часто возникают при моделировании процессов, где зависимость переменной описывается двумя независимыми аргументами: например, в теории газовой динамики для описания стационарных потоков, в задачах теплопередачи со стационарным распределением температуры, в теории электростатики при определении потенциала поля и в экономике при моделировании оптимальных стратегий с использованием пространственно-временных аргументов.

Метод решения таких уравнений существенно отличается от подходов к обыкновенным дифференциальным уравнениям. Важным инструментом является понятие характеристик – кривых на плоскости (x, y) , в результате чего задача сводится к обычной задаче. Кроме того, если известно частное решение (главный интеграл) соответствующего однородного уравнения, становится возможным перейти к новым переменным, в которых исходное неоднородное уравнение преобразуется в уравнение с разделяющимися переменными.

В данном обзоре подробно рассматриваются три основных подхода к решению линейных неоднородных уравнений первого порядка:

- переход к новым переменным на основе известного интеграла однородного уравнения.
- метод характеристик,
- применение вспомогательного однородного уравнения с тремя независимыми переменными.

Далее задача Коши формулируется в классической и обобщенной форме, и дается алгоритм ее решения. Заключительная часть работы состоит из конкретных примеров, иллюстрирующих применение указанных методов. Основными использованными литературными источниками были [1-2].

Основная часть

Методы решения. Рассмотрим линейное неоднородное уравнение первого порядка с двумя независимыми переменными вида:

$$a(x, y)u_x + b(x, y)u_y = c(x, y, u), \quad (1)$$

где $u = u(x, y)$ – неизвестная функция, $u_x = \partial u / \partial x$, $u_y = \partial u / \partial y$, и a, b, c известны и довольно гладкие.

Общее решение уравнения (1) представляется в виде

$$u(x, y) = u_h(x, y) + u_p(x, y),$$

Где $u_h(x, y)$ – общее решение соответствующего однородного уравнения для $c = 0$ $Au_p(x, y)$ – произвольное частное решение неоднородного уравнения.

Метод перехода к новым переменным. Пусть известно нетривиальное частное решение (главный интеграл). $\Phi(x, y)$ однородное уравнение

$$a(x, y)u_x + b(x, y)u_y = 0,$$

то есть функция $\Phi(x, y)$ удовлетворяет

$$a(x, y)\Phi_x + b(x, y)\Phi_y = 0.$$

Давайте введём новые переменные.

$$\xi = \Phi(x, y), \quad \eta = \Psi(x, y),$$

Где $\Psi(x, y)$ - вторая функция, независимая от Φ , таким образом, переход $(x, y) \mapsto (\xi, \eta)$ локально обратимая.

В новых переменных исходное уравнение (1) преобразуется в уравнение с разделяемыми переменными относительно ξ при фиксированном η :

$$a^*(\xi, \eta) \frac{\partial u}{\partial \xi} = c^*(\xi, \eta, u), \quad (2)$$

где $a^*(\xi, \eta)$ и $c^*(\xi, \eta, u)$ – функции, полученные в результате подстановки $(x, y) \rightarrow (\xi, \eta)$.

Общее решение (2) записывается как

$$F(\eta, u) = \int \frac{d\xi}{a^*(\xi, \eta)} [c^*(\xi, \eta, u)]^{-1} + G(\eta), \quad (3)$$

где F и G – произвольные функции, и интеграл берется в фиксированной точке η . Вернемся к переменным. x, y достаточно заменить $\xi = \Phi(x, y), \eta = \Psi(x, y)$.

Метод характеристики. Характеристическая система для уравнения (1) задается системой обыкновенных дифференциальных уравнений:

$$\frac{dx}{ds} = a(x, y), \quad \frac{dy}{ds} = b(x, y), \quad \frac{du}{ds} = c(x, y, u). \quad (4)$$

Его интегральные кривые $(x(s), y(s), u(s))$ называются характеристиками.

Если найдены два независимых первых интеграла характеристической системы, то функции

$$I_1(x, y, u), \quad I_2(x, y, u),$$

удовлетворяющие уравнения

$$a \frac{\partial I_i}{\partial x} + b \frac{\partial I_i}{\partial y} + c \frac{\partial I_i}{\partial u} = 0, \quad i = 1, 2,$$

тогда общее решение неоднородного уравнения (1) дается соотношением

$$\Phi(I_1(x, y, u), I_2(x, y, u)) = 0, \quad (5)$$

где Φ – произвольная функция двух аргументов.

Вспомогательный метод однородных уравнений. Рассмотрим вспомогательное линейное однородное уравнение

$$a(x, y)w_x + b(x, y)w_y + c_0(x, y)w = 0, \quad (6)$$

где $w(x, y)$ – неизвестная функция и $c_0(x, y)$ – данный.

Общий интеграл уравнения (6) имеет вид

$$\Psi(x, y, w) = C,$$

где Ψ – интегральная поверхность. Тогда решение исходного неоднородного уравнения (1) получается из уравнения

$$\Psi(x, y, u(x, y)) = 0,$$

Что может дать неявное или явное выражение для $u(x, y)$.

Проблема Коши. Формулировка.

Классическая версия. Найдите решение $u(x, y)$ уравнение (1), удовлетворяющее начальному условию на кривой $x = 0$:

$$u(0, y) = \phi(y),$$

где $\phi(y)$ — заданная функция.

Обобщенная версия. Исходные данные представлены на произвольной кривой, определенной параметрически:

$$x = X(\tau), \quad y = Y(\tau), \quad u = U(\tau), \quad \tau \in [\alpha, \beta].$$

В данном случае смысл таков: u положение на кривой определяется функцией $U(\tau)$.

Решение задачи Коши. Алгоритм решения обобщенной задачи Коши включает в себя:

1. Построение характеристической системы (4).
2. Нахождение двух независимых первых интегралов $I_1(x, y, u)$ и $I_2(x, y, u)$.
3. Расчет значений

$$C_1(\tau) = I_1(X(\tau), Y(\tau), U(\tau)), \quad C_2(\tau) = I_2(X(\tau), Y(\tau), U(\tau))$$

для всех τ .

4. Исключение параметров τ из уравнений $I_1 = C_1(\tau)$ и $I_2 = C_2(\tau)$ чтобы получить соотношение между x, y, u .

Таким образом, решение устанавливается явно или неявно на основе характеристик и исходных данных.

Конкретные примеры.

Пример 1. Уравнение

$$u_x + u = e^x, \tag{7}$$

где предполагается, что решение $u(x, y)$ не зависит от y . Тогда (7) превращается в обычное уравнение

$$\frac{du}{dx} + u = e^x.$$

Мы ищем конкретное решение в форме $u_p(x, y) = v(x)$ Мы заменяем:

$$v'(x) + v(x) = e^x \Rightarrow v(x) = \frac{e^x}{2} + Ce^{-x}.$$

Тогда общее решение исходного уравнения будет следующим:

$$u(x, y) = \frac{e^x}{2} + A(y)e^{-x},$$

где $A(y)$ — произвольная функция y получено из решения однородного уравнения $u_x + u = 0$.

Пример 2. Уравнение

$$xu_x + yu_y = xy. \quad (8)$$

Сначала решим соответствующее однородное уравнение:

$$xu_x + yu_y = 0.$$

Характеристика системы:

$$\frac{dx}{ds} = x, \quad \frac{dy}{ds} = y, \quad \frac{du}{ds} = 0.$$

Из первых двух уравнений $dy/dx = y/x \Rightarrow y = C_1x$ то есть первый интеграл $I_1 = y/x$ Третье уравнение дает второй интеграл. $I_2 = u$ вдоль характеристики. Общее решение однородного уравнения:

$$u_h(x, y) = F\left(\frac{y}{x}\right).$$

Для частного решения $u_p(x, y)$ мы верим $u_p = A(x)y$. Затем

$$u_{p,x} = A'(x)y, \quad u_{p,y} = A(x).$$

Подстановка в (8):

$$x(A'(x)y) + yA(x) = xy \Rightarrow xA'(x) + A(x) = x.$$

Это обычное уравнение первого порядка, решенное методом интегрирующего множителя:

$$A(x) = x - \frac{C_3}{x}.$$

Давайте выберем $C_3 = 0$, мы получаем $A(x) = x$. Означает,

$$u_p(x, y) = xy.$$

Общее решение (8):

$$u(x, y) = F\left(\frac{y}{x}\right) + xy,$$

где F — произвольная функция от одного аргумента.

Пример 3. Задача Коши для (8) с начальными данными на кривой $x + y = 1, u(1, y) = y$. Мы определяем кривую параметрически: $x = 1 - \tau, y = \tau, u(1 - \tau, \tau) = \tau$ Характерная система:

$$\frac{dx}{ds} = x, \quad \frac{dy}{ds} = y, \quad \frac{du}{ds} = xy.$$

Решив первые два уравнения, получаем $x(s) = Ce^s, y(s) = C_1 Ce^s$, где $C_1 = y/x$ Затем вдоль характеристики

$$\frac{du}{ds} = x(s)y(s) = C^2 C_1 e^{2s} \Rightarrow u(s) = \frac{C^2 C_1}{2} e^{2s} + C_2.$$

Мы заменяем $e^s = x/C$, мы получаем

$$u = \frac{C_1}{2} x^2 + C_2, \quad C_1 = \frac{y}{x}, \quad C_2 - \text{const.}$$

Итак, второй интеграл:

$$I_2 = u - \frac{1}{2} xy.$$

Общее решение в форме (5):

$$u - \frac{1}{2} xy = G\left(\frac{y}{x}\right).$$

С учетом начальных условий $x = 1 - \tau, y = \tau$, мы получаем

$$\tau - \frac{1}{2}(1 - \tau)\tau = G\left(\frac{\tau}{1 - \tau}\right) = \frac{\tau}{2} \frac{1 + \tau}{1 + \tau} = \frac{\tau}{2}.$$

Следовательно,

$$G(\mu) = \frac{\mu}{2(1 + \mu)}, \quad \mu = \frac{y}{x}.$$

В конце концов

$$u(x, y) = \frac{1}{2} xy + \frac{y}{2(x + y)}.$$

Заключение

В обзоре систематизированы классические методы решения линейных неоднородных дифференциальных уравнений в частных производных первого порядка. Показано, что:

- Метод перехода к новым переменным через главный интеграл однородного уравнения позволяет свести задачу к уравнению с разделяемыми переменными;
- Характеристический метод дает общее решение посредством первых интегралов характеристической системы;
- Для получения неявных решений исходного уравнения можно использовать вспомогательное однородное уравнение с тремя переменными.

Приводятся примеры, демонстрирующие применение каждого из методов, включая построение частных решений, общее решение однородного уравнения и решение задачи Коши.

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Peculiarities of Life Expectancy Across the Regions of countries (Kazakhstan)

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Abstract

The current research analyzes factors influencing life expectancy among various regions of Kazakhstan by applying official statistics and correlation methods. According to the results obtained, the strongest correlations are found for such factors as the size of catering market, spending on R&D activities, and the number of institutions providing higher education. Moreover, significant correlations are identified between life expectancy and employment rate, population, and marriage rate. Using these findings, regions of Kazakhstan will be divided into several groups for comparison purposes in order to find out how important factors influence longevity differently in various regions.

Keywords: life expectancy, regional analysis, Kazakhstan, correlation analysis, socio-economic factors, education, regional disparities.

1. Introduction

The life expectancy is considered one of the most important markers of social and economic development of the state. It shows not only the health state of the population, but also reveals such factors as the level of education, jobs available, as well as the quality of life. Though, there are regional differences concerning life expectancy in Kazakhstan during the last decades. The goal of this study is to find out what factors cause the regional disparities in life expectancy in Kazakhstan. As a result of correlation analysis, the strongest correlations were found between the variables representing such factors as education level, expenses on research and development and services sector. The next step in this research includes clustering of regions according to the set of factors and comparison of the influence of the mentioned factors on life expectancy among different clusters.

1.1 Literature Matrix

Title	Author(s), Year	Methodology	Key Findings	Connection to our work
Factors affecting life expectancy in Kazakhstan	A.Zh.Panzabekova, Ivan E. Digel 2020	The study is based on regression and correlation analysis. Data were selected based on two criteria: availability of longterm statistical data and potential impact on life expectancy. A two-factor power	The study used regression models to analyze the impact of socio-economic factors on life expectancy in the regions of Kazakhstan. The results show that economic factors have the most significant influence, while some relationships require further research.	We used the same methods as in the article, but not just for Kazakhstan's regions, but for the entire world. And you can see a trend that within individual countries and within each country, the indicators vary according to certain logics.
		regression model was constructed using Microsoft Excel.		

<p>Life expectancy and its determining elements: A study for the Czech Republic at the beginning of the 21th century</p>	<p>Vojtech Korbelius, Mgr. Michal Paulus, 2025</p>	<p>The study developed a life expectancy model for the Czech Republic using district-level data and grouped explanatory variables into three categories: socio-economic factors, health-care factors, and environmental pollution indicators.</p>	<p>The study found that pollution significantly reduces life expectancy, while a higher proportion of people aged 65 is positively associated with longer life expectancy. It also showed that health-care factors such as access to doctors, pharmaceutical revenues, and environmental investments play important roles.</p>	<p>The study provides a valuable framework for our analysis of life expectancy across the regions of Kazakhstan. By examining socio-economic, healthcare, and environmental determinants of longevity, it helps identify factors that may explain regional differences in life expectancy within Kazakhstan.</p>
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Modelling of life expectancy in the world	V. A. Shtun, 2021	Econometric analysis using multiple linear regression based on cross-country data (126 countries). Statistical testing of variables and model diagnostics were applied to determine significant factors affecting life expectancy.	The study found that life expectancy is significantly influenced by access to clean drinking water, government health expenditure, vaccination coverage, electricity access, and GDP per capita. Negative effects were found for alcohol consumption and CO ₂ emissions. Some variables such as unemployment, education level, and smoking were not statistically significant in the global model.	This study supports our diploma research by demonstrating how statistical modeling can be used to analyze determinants of life expectancy across countries. It provides methodological support for our machine learning approach and helps justify the selection of socioeconomic, behavioral, and environmental variables used in our life expectancy prediction model.
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2. Methodology

The regression model was used to study the relationship between economic, social, and environmental factors and life expectancy. This approach allows the identification of factors that are most strongly associated with life expectancy and provides a global comparative analysis.

For each independent variable, a simple linear regression model was constructed:

$$v_i = m_1 + m_2 u_i \quad (1)$$

- v_i is the life expectancy for observation i ,
- u_i is an independent variable (factor) that influences life expectancy,
- m_1 is the intercept representing the baseline level when $u_i = 0$,
- m_2 is the slope coefficient indicating the change in life expectancy when u_i increases by one unit.

To examine the relationship between life expectancy and selected factors, the correlation analysis is applied. In this study, the simple linear correlation coefficient is used to measure the strength and direction of the relationship between variables.

The correlation coefficient is calculated as follows:

$$k_{uv} = \frac{\sum_{i=1}^n u_i v_i - n \cdot \bar{u} \bar{v}}{\sqrt{(\sum_{i=0}^n u_i^2 - n \cdot \bar{u}^2)(\sum_{i=0}^n v_i^2 - n \cdot \bar{v}^2)}} \quad (2)$$

The correlation coefficient ranges from -1 to +1. Values close to +1 indicate a strong positive relationship, values close to -1 indicate a strong negative relationship, and values near 0 indicate no linear relationship.

The coefficient of determination is defined as the proportion of total variation explained by the regression model:

$$K^2 = \frac{\sum_{i=0}^n (\hat{v}_i - \bar{v})^2}{\sum_{i=0}^n (v_i - \bar{v})^2}$$

A higher K^2 indicates a better explanatory power of the independent variable.

3. Regression analysis of Factors Affecting Life Expectancy in Kazakhstan

A data set was compiled for 20 regions of Kazakhstan. The following variables were included in the analysis: labor productivity, government expenditure on R&D, number of universities, number of marriages, population, number of employed, divorce rate, the size of the public catering market and so on.

Name of Indicators	Designation
Labor productivity by region, tenge	lbr
Government expenditure on R&D by region, tenge	gov
Number of higher education institutions	uni
Number of marriages	mrg
Population, total	pop
Number of employed by region	empl
Number of divorces	div
Average monthly pension amount by region, tenge	pens
Median income of the population by region, tenge	aversal
Emissions of liquid and gaseous pollutants by region, ton	co2
The size of the public catering market by region, tenge	cat

table1 Socio-Economic Indicators Used for the Analysis of Kazakhstan

To conduct a correlation analysis of factors influencing life expectancy, were used official statistical data provided by the Statistics Committee of the Republic of Kazakhstan (stat.gov.kz). It should be noted that slightly different factors were used for Kazakhstan, as data for some indicators presented in international sources were unavailable. The designations of the indicators used are presented in Table 2.

Indicators	Correlation coefficient (k)
lbr	0,22
cat	0,76
gov	0,74
uni	0,71
mrg	0,69
pop	0,68
empl	0,67
div	0,53
pens	0,30
aversal	0,274
co2	0,36

table 2 Correlation coefficients between indicators

Since life expectancy can vary depending on continental factors, cities were grouped by regions to analyze which variables have the greatest impact on life expectancy in each region group. Correlation coefficients were calculated using formula 2. The results are presented in Table 3.

North Kaz	k	k ²	West Kaz	k	k ²	Central Kaz	k	k ²	East Kaz	k	k ²	South Kaz	k	k ²
lbr	0,62	0,39	lbr	0,25	0,06	lbr	-0,95	0,91	lbr	-0,95	0,92	lbr	0,83	0,70
gov	0,47	0,23	gov	0,72	0,52	gov	0,47	0,22	gov	-0,92	0,85	gov	0,87	0,76
uni	0,99	0,99	uni	-0,81	0,66	uni	0,90	0,81	uni	-0,76	0,59	uni	0,97	0,93
mrg	0,99	0,99	mrg	0,40	0,16	mrg	0,82	0,68	mrg	-0,38	0,14	mrg	0,62	0,38
pop	0,98	0,97	pop	0,11	0,01	pop	0,87	0,56	pop	-0,91	0,83	pop	0,65	0,42
empl	0,98	0,97	empl	-0,16	0,02	empl	0,92	0,86	empl	-0,92	0,85	empl	0,69	0,47
div	0,49	0,25	div	-0,47	-0,22	div	0,85	0,72	div	-0,98	0,97	div	0,77	0,60
pens	-0,29	0,09	pens	0,81	0,66	pens	0,25	0,06	pens	-0,97	0,95	pens	0,66	0,44
aversal	-0,91	0,84	aversal	0,21	0,04	aversal	0,81	0,67	aversal	0,85	0,73	aversal	0,74	0,54
co2	0,55	0,31	co2	0,63	0,40	co2	0,33	0,11	co2	-0,79	0,64	co2	0,95	0,90
cat	0,95	0,92	cat	0,50	0,25	cat	0,72	0,52	cat	-0,90	0,82	cat	0,88	0,77

table 3 Correlation between life expectancy and factors in Kazakhstan

4. From Data to Application: Predicting Life Expectancy

In this chapter, a predictive model for life expectancy estimation was developed using the Multiple Linear Regression approach.

In our previous work (“Factors Affecting Life Expectancy Worldwide and Kazakhstan”) we worked with Regression analysis for 207 countries and predictive model was constructed using MSEExcel. For this article an application was constructed with the Scikit-learn library in the programming language Python, using the LinearRegression() method. The dataset used in this study contains data from over 200 countries and includes a variety of demographic, economic, environmental and lifestyle indicators that could affect life expectancy.

The application interface was designed to be simple and user-friendly. Users can select a country and adjust several lifestyle-related parameters, including smoking status, alcohol consumption, obesity level, gender, and happiness score.

Life Expectancy Calculator

Select country
Morocco

Gender
Male

Smoking
No

Alcohol
No

Obesity
No

Happiness Level
7.35

Predict

Predicted life expectancy: 70.4 years

Estimated range: 67.5 - 73.3 years

Average life expectancy in Morocco: 75.5

figure 1 Life expectancy calculator

After entering the required information and pressing the prediction button, the application processes the data and calculates the estimated life expectancy value using the trained regression model.

The application displays:

- predicted life expectancy;
- estimated prediction interval;
- average life expectancy of the selected country.

5. Results and Discussion

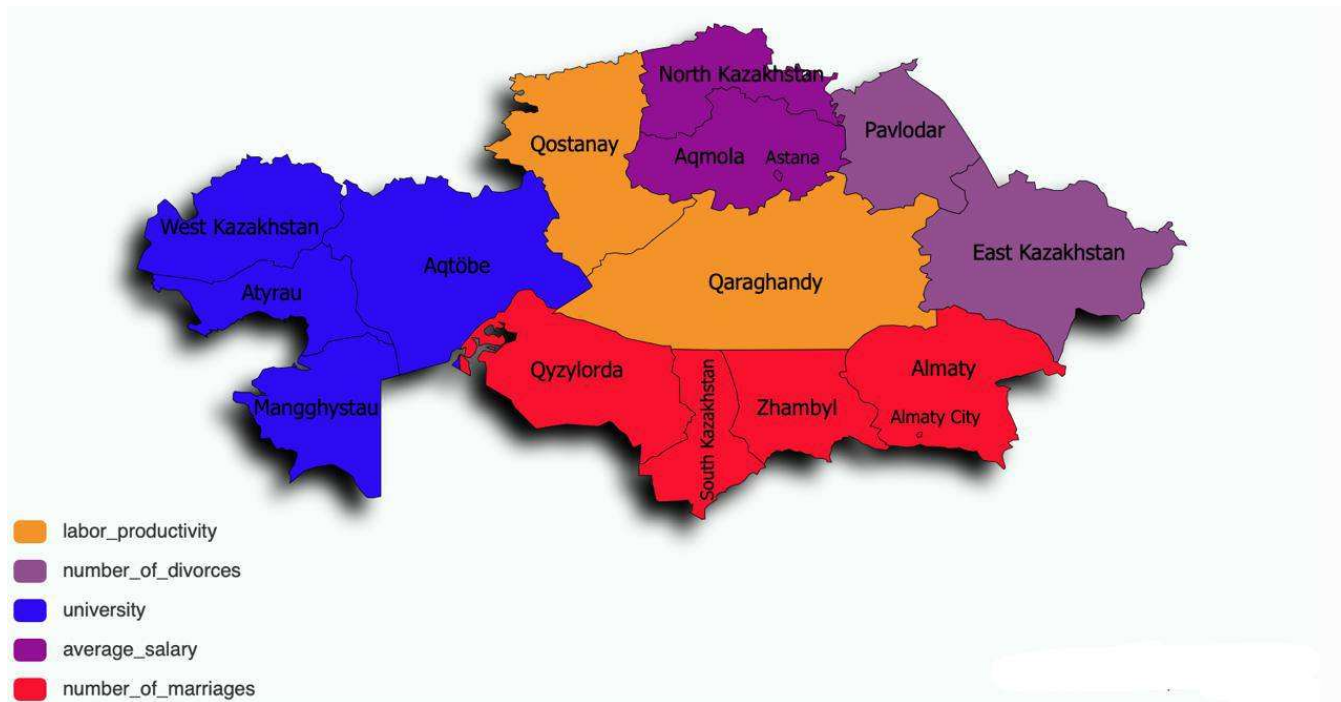


figure 2 The factors that have the negative impact

Figure 2 shows the factors with the strongest negative impact on life expectancy in each region of Kazakhstan. In the western region, the number of universities has the greatest negative impact, whereas in the eastern region, the number of divorces has the strongest negative impact. In the northern region, average wages are considered the factor with the strongest negative correlation. In the central region, the size of the working-age population has the strongest negative impact, whereas in the southern region, the number of marriages has the strongest negative correlation with life expectancy.

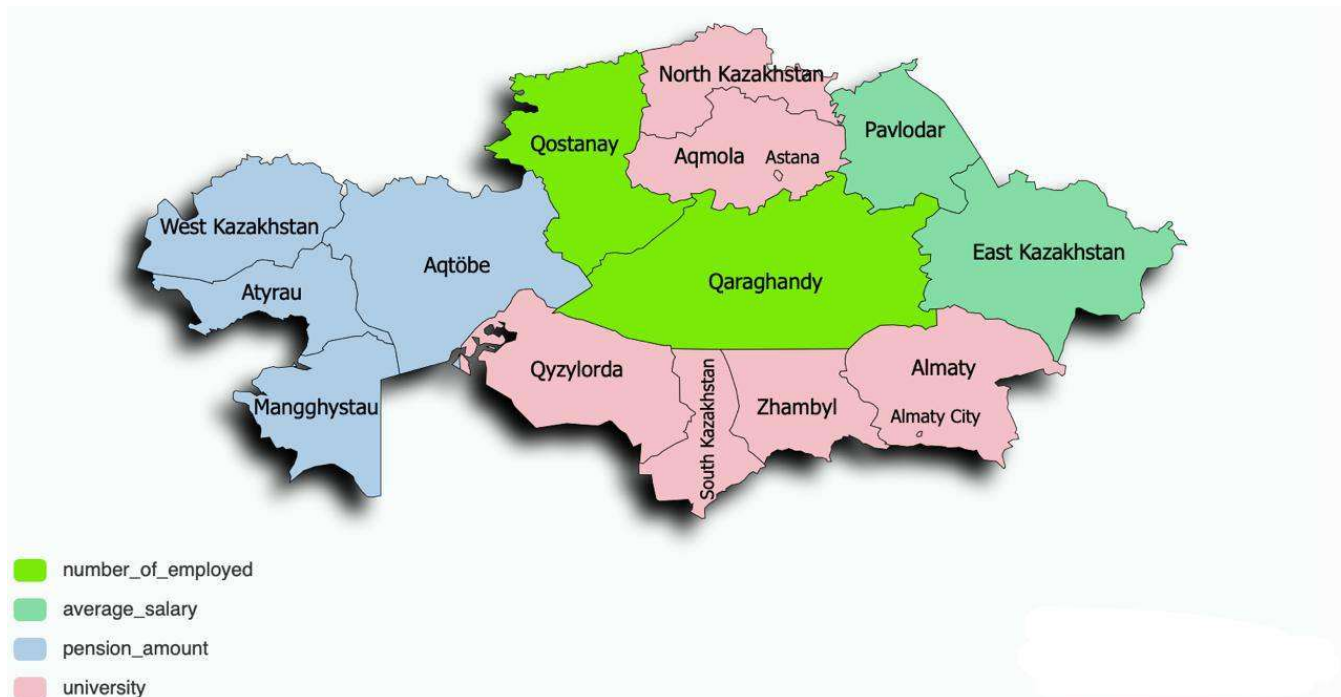


figure 3 The factors that have the positive impact

Figure 3 shows the factors with the strongest positive correlation with life expectancy in various regions of Kazakhstan. In Western Kazakhstan, it is considered that pension levels have the

greatest positive impact. In Eastern and Northern Kazakhstan, average wages show the strongest positive correlation with life expectancy. In Central Kazakhstan, the number of people in employment has the greatest positive effect, whereas in Southern Kazakhstan, the number of universities shows the strongest positive correlation with life expectancy. These findings show that the factors exerting the strongest positive influence on life expectancy vary significantly from region to region, reflecting different social, economic and demographic conditions.

6. Conclusion

This study examined the relationship between socio-economic and demographic factors, on the one hand, and life expectancy, on the other, across various regions of Kazakhstan. Using correlation and comparative analysis, both positive and negative links were identified between life expectancy and a range of regional indicators, including average wages, employment rates, the pension ratio, the number of higher education institutions, the number of marriages and divorces, as well as characteristics of the working-age population.

The results show that the factors most closely associated with life expectancy vary significantly by region. Positive correlations were mainly linked to economic and educational indicators, such as average wages, employment rates, pension amount and the number of higher education institutions. Conversely, the factors showing the strongest negative correlations varied by region and included variables such as the number of divorces, marriages, the size of the labor productivity, average salary and the number of universities.

These regional differences suggest that life expectancy is not influenced by a single overarching factor, but rather by a complex interplay of social and economic conditions. The findings highlight the importance of regional approaches in the formulation of public policy, e.g.

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Algorithm for the Best Functional Regression Model

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Abstract

Regression analysis is widely used in science, engineering, economics and many other fields for modeling relationships between variables and for predicting future observations. Selecting an appropriate regression model is a crucial step towards reliable results. In this work, we consider some popular regression models and discuss their suitability for different types of data. The alternative model is evaluated and compared to other models using statistical measures through a Python-based approach. The results highlight the importance of model selection and provide a simple framework in order to decide the most appropriate regression model for a given dataset.

Keywords

Regression, Pearson correlation coefficient, Spearman correlation coefficient, Coefficient of determination, Adjusted R^2 , Functional regression.

Introduction

Most users who work with datasets tend to reach for regression now and then. These methods arrays everywhere - from math class to stock forecasts, even robot brains. What makes linear versions stick around? There are straightforward answers, mostly. When things get twisty between factors, polynomials step in instead. Not every field uses them the same way, yet they still show up constantly.

Choosing the right model isn't always straightforward when working with regression. While one version might fit well, another could miss patterns in the data. Accuracy shifts depending on the structure chosen, so comparing options matters. Some methods reveal weaknesses others hide, simply by how they measure error. Tools like adjusted R-squared help spot which setup works better. Instead of guessing, analysts lean on these metrics to guide decisions. Each number gives a hint - not proof - about what fits most naturally.

This research looks into how well different regression models perform, using a custom-built Python program to pick the best one based on standard statistical measures. While some methods show stronger results, others fall short under typical evaluation rules. A closer look at performance reveals patterns that favor certain models depending on data traits. Instead of relying on assumptions, the tool uses clear metrics to guide choices. Each model's outcome gets weighed through consistent testing procedures. Depending on the dataset, the top choice can shift noticeably. Through systematic comparison, one approach often stands out without needing

expert guesswork. (Considered studies: [2], [1], [4], [3])

Literature Review

Table 1: Literature Review

Link	Author	Main idea	Connection to our work
Regression Analysis	Marko Sarstedt, Erik Mooi	Discusses regression analysis as a tool for modeling relationships between variables and making predictions.	Supports the general methodology of regression modeling. Unlike this work, our study emphasizes automatic model selection among several regression types.
Multivariate Polynomial Regression in Data Mining: Methodology, Problems and Solutions	Priyanka Sinha	Examines polynomial regression models and their applications in data mining and predictive analysis.	Demonstrates the usefulness of nonlinear regression models. Our work compares polynomial models with linear regression using statistical criteria.
Метрики качества линейных регрессионных моделей	Loginom Blog	Describes common quality metrics used to evaluate regression models, including measures of goodness of fit.	Provides evaluation criteria used in our study. We apply these metrics within a Python program to identify the most suitable regression model automatically.
Applied Multivariate Statistical Analysis	Richard Johnson, Dean Wichern	Presents the theoretical foundations of multivariate statistical analysis, including regression methods and model evaluation techniques.	Provides the statistical background for regression analysis. Our work focuses on implementing and comparing specific regression models in Python.

Methodology

To identify criteria for choosing the best regression model we have calculated the metrics for different functions, constructed plots and Star Radar Plots ([2]) and compared results to make decisions.

We chose four functions for which scatter plots were constructed:

$$\begin{aligned}
 &y = x, \quad y = x^2, \quad y = x^3, \quad y = \sin(x), \quad y = \cos(x), \quad y = e^x, \\
 &y = e^x - 1, \quad y = \ln(x), \quad y = \ln(x - 1), \quad y = \ln(x + 1), \quad (1) \\
 &y = (x - 1)^2 - 1, \quad y = (x - 2)^2 - 1, \quad y = (x - 1)^3 - 1, \quad y = (x - 2)^3 - 1
 \end{aligned}$$

For each function we considered several intervals of an independent variable x :

[0; 10], [1; 11], [2; 12], [3; 13], [4; 14], [5; 15]

Each interval contains 21 observations with a step size of 0,5. For instance, on the interval [0;10], where the following values are chosen:

0, 0.5, 1, 1.5, ... , 9, 9.5, 10

Consider the function $y = (x - 1)^2 - 1$. We calculated r_{xy} (Pearson correlation coefficient), r_s (Spearman correlation coefficient), also R^2 (Coefficient of determination) for linear, quadratic and cubic regression models and Adjusted R^2 for them. The values of coefficients for predicted models \hat{y} were calculated using OLS method. (1)

$Y=(X-1)^2-1$						
x-range	0 to 10	1 to 11	2 to 12	3 to 13	4 to 14	5 to 15
r(xy)	0,9475	0,9655	0,9756	0,9819	0,9861	0,9889
r(s)	0,9877	1,0000	1,0000	1,0000	1,0000	1,0000
R ²	0,8978	0,9321	0,9519	0,9642	0,9723	0,9780
a	-15,8333	33,1667	-39,8333	-54,8333	-71,8333	-90,8300
b	8,0000	6,0000	12,0000	14,0000	16,0000	18,0000
R ² (quadratic)	0,9796	0,9803	0,9804	0,9781	0,9726	0,9629
a ₂	-8,9724	-16,8607	-26,9503	-39,4833	-54,9597	-74,0786
b ₂	2,5552	4,2297	5,7887	7,2917	8,8005	10,3661
c ₂	0,5960	0,5457	0,5260	0,5237	0,5315	0,5458
R ² (cubic)	0,9993	0,9998	0,9999	1,0000	1,0000	1,0000
a ₃	-1,8390	-2,8045	-3,8586	-4,4932	-5,2619	-6,0088
b ₃	-0,0094	-0,0079	0,0961	0,0018	0,0005	0,0002
c ₃	0,5479	0,6343	0,6776	0,7348	0,7671	0,7922
d ₃	0,0279	0,0193	0,0148	0,0108	0,0085	0,0068
R ² _{adj} (quad)	0,9773	0,9782	0,9782	0,9757	0,9696	0,9588
R ² _{adj} (cubic)	0,9992	0,9998	0,9999	1,0000	1,0000	1,0000

Figure 1: Metrics of $y = (x - 1)^2 - 1$

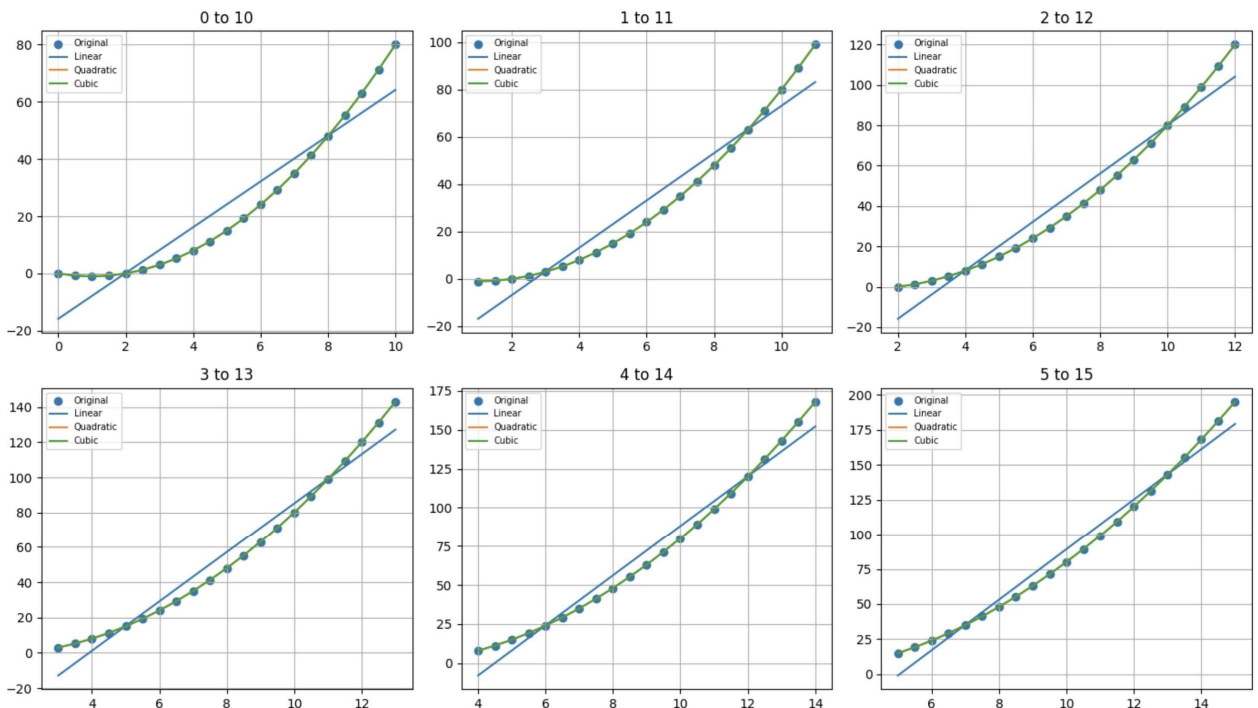


Figure 2: Scatter plots of $y = (x - 1)^2 - 1$

The results (2) show a consistently high Pearson correlation coefficient r_{xy} , indicating a strong linear association between x and y . However, a high linear correlation does not necessarily imply that a linear model is the most appropriate representation of the data. The Spearman correlation coefficient r_s is equal to 1 (or very close to 1) across almost all intervals, which confirms a perfect monotonic relationship between the variables, though it does not distinguish between linear and nonlinear structures.

To evaluate model performance more precisely, we consider the coefficient of determination R^2 and its adjusted version. The results show that both R^2 and Adjusted R^2 increase as the polynomial degree increases, indicating that higher-order models explain more variance in the data. Importantly, the adjusted R^2 does not penalize the higher-degree models in this case, suggesting that additional parameters are contributing meaningful explanatory power rather than unnecessary complexity.

Additionally, shifting the x -interval slightly improves the overall fit, further stabilizing the model performance. Based on the consistently highest R^2 and adjusted R^2 values, the cubic model $\hat{y} = a + bx + cx^2 + dx^3$ provides the best fit for the data among the tested models.

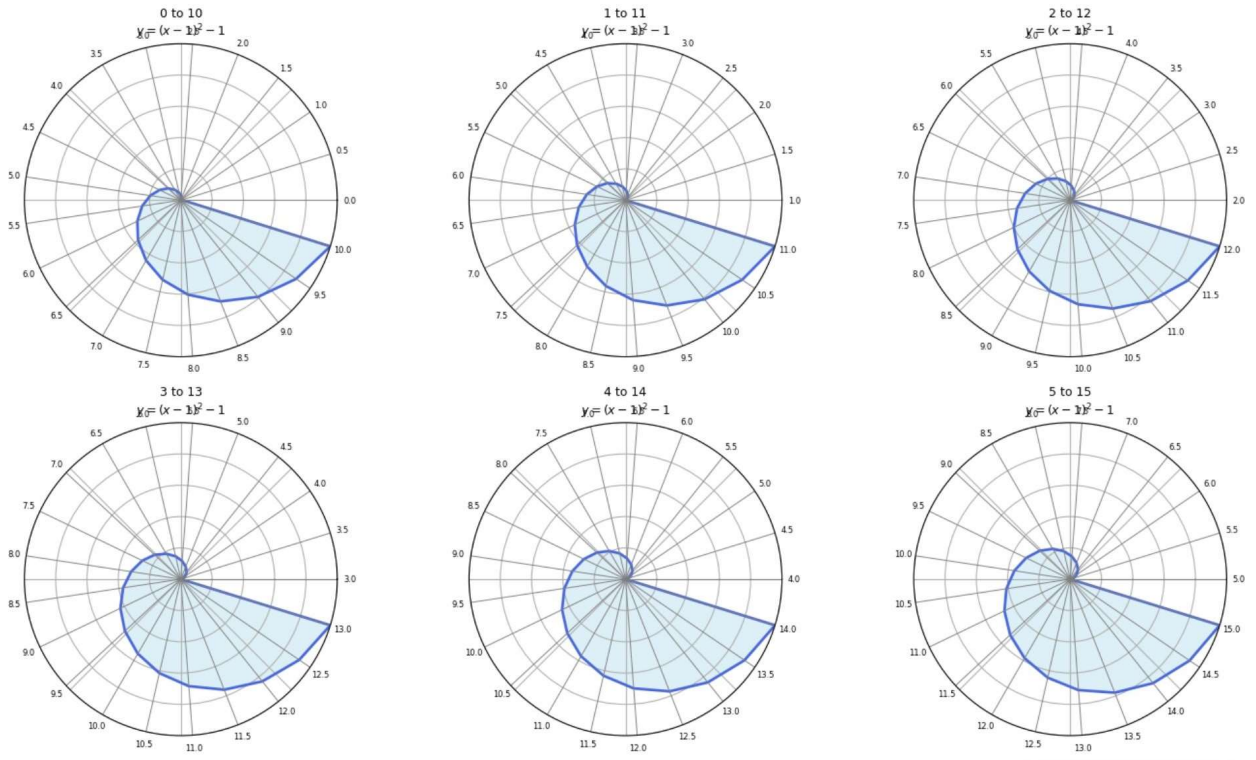


Figure 3: Star plots of $y = (x - 1)^2 - 1$

In addition to the scatter plot, star plots ([2]) were made for each function over the same intervals. ([3]) The star plots show each observation as a ray from the center of a circle. The length of the ray is representative of the value of the function at a given x value.

The corresponding values of the function plotted as ray lengths. The star plots show how the functions behave. For $y = (x - 1)^2 - 1$ the star shapes become more elongated as the interval moves to the right.

Consider the function $y = \cos(x)$.

Y=COS(X)						
x-range	0 to 10	1 to 11	2 to 12	3 to 13	4 to 14	5 to 15
r(xy)	-0,2943	-0,0947	0,2131	0,3017	0,1381	-0,1794
r(s)	-0,3065	-0,1000	0,2065	0,3390	0,1481	-0,1558
R^2	0,0866	0,0090	0,0454	0,0910	0,0191	0,0322
a_1	-0,0711	-0,0307	-0,4655	-0,5625	-0,1242	0,3403
b_1	0,3100	-0,0207	0,0500	0,0700	0,0300	0,5403
R^2 (quadratic)	0,0921	0,0428	0,0481	0,0914	0,0310	0,0295
a_2	0,2533	-0,1306	-0,4782	-0,4854	-0,2168	0,5293
b_2	-0,0273	0,0349	0,0548	0,0396	0,0114	-0,0346
c_2	-0,0048	-0,0053	-0,0005	0,0026	0,0027	-0,0004
R^2 (cubic)	0,2004	0,1405	0,0025	0,1219	0,1390	0,0560
a_3	-0,0897	-0,3912	-0,1950	0,0430	0,6908	0,8389
b_3	-0,0071	-0,0016	-0,1257	-0,0043	-0,0006	0,0005
c_3	0,0384	0,0349	0,0328	-0,0137	-0,0288	-0,0193
d_3	-0,0047	-0,0035	-0,0018	0,0014	0,0021	0,0011
R^2_adj (quad)	-0,0088	-0,0636	-0,0576	-0,0096	-0,0767	-0,0783
R^2_adj (cubic)	0,0593	-0,0111	-0,1734	-0,0330	-0,0128	-0,1104

Figure 4: Metrics of $y = \cos(x)$

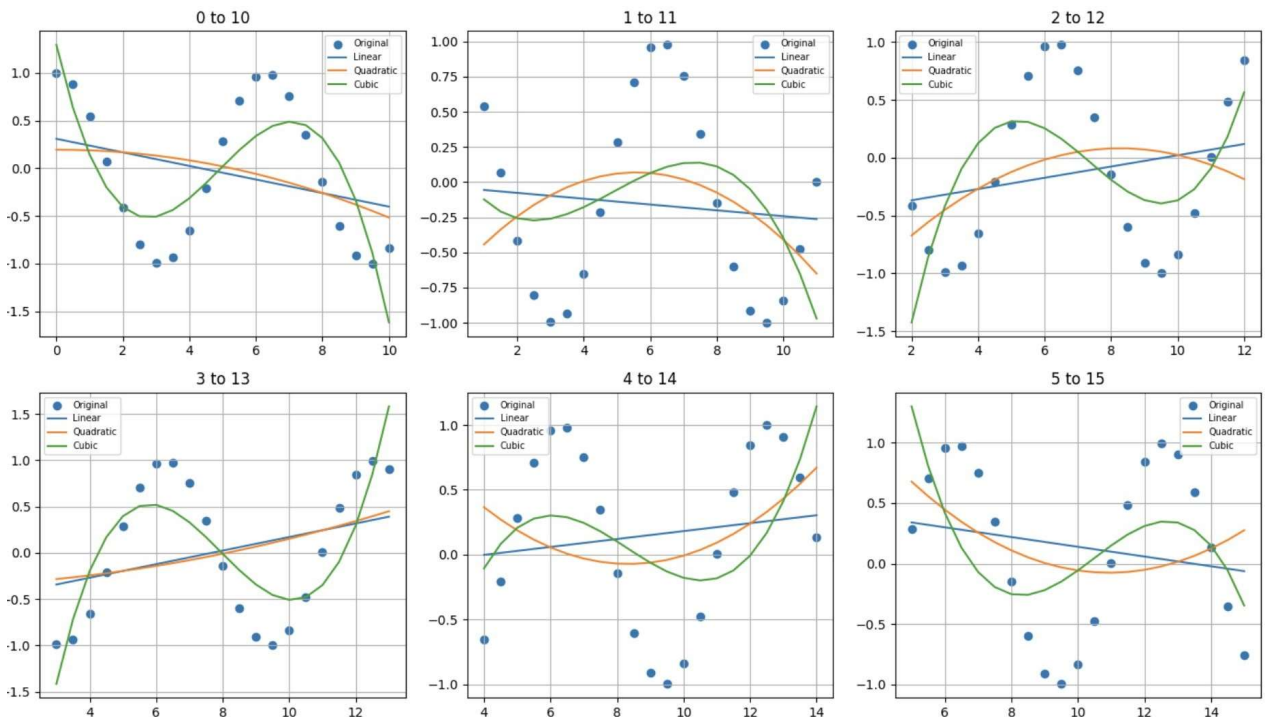


Figure 5: Scatter plots of $y = \cos(x)$

For $y = \cos(x)$ the results ([4], [5]) show a weak and unstable relationship between x and y across all x-ranges. The correlation values fluctuate around zero and even change sign,

confirming that there is no consistent linear or monotonic pattern due to the periodic nature of the cosine function.

Linear regression performs poorly with very low R^2 values (0.01–0.09), meaning it explains almost none of the variation. Quadratic models do not improve the fit, and their Adjusted R^2 values are negative, showing no real predictive value. Cubic models perform slightly better in some intervals (up to $R^2=0.20$) but results remain inconsistent and still weak overall.

Overall, polynomial regression (linear, quadratic, cubic) is not suitable for modeling $\cos(x)$ over shifting intervals because the function is periodic. The model fit depends heavily on the chosen range, and none of the low-degree polynomials can reliably capture the oscillating behavior.

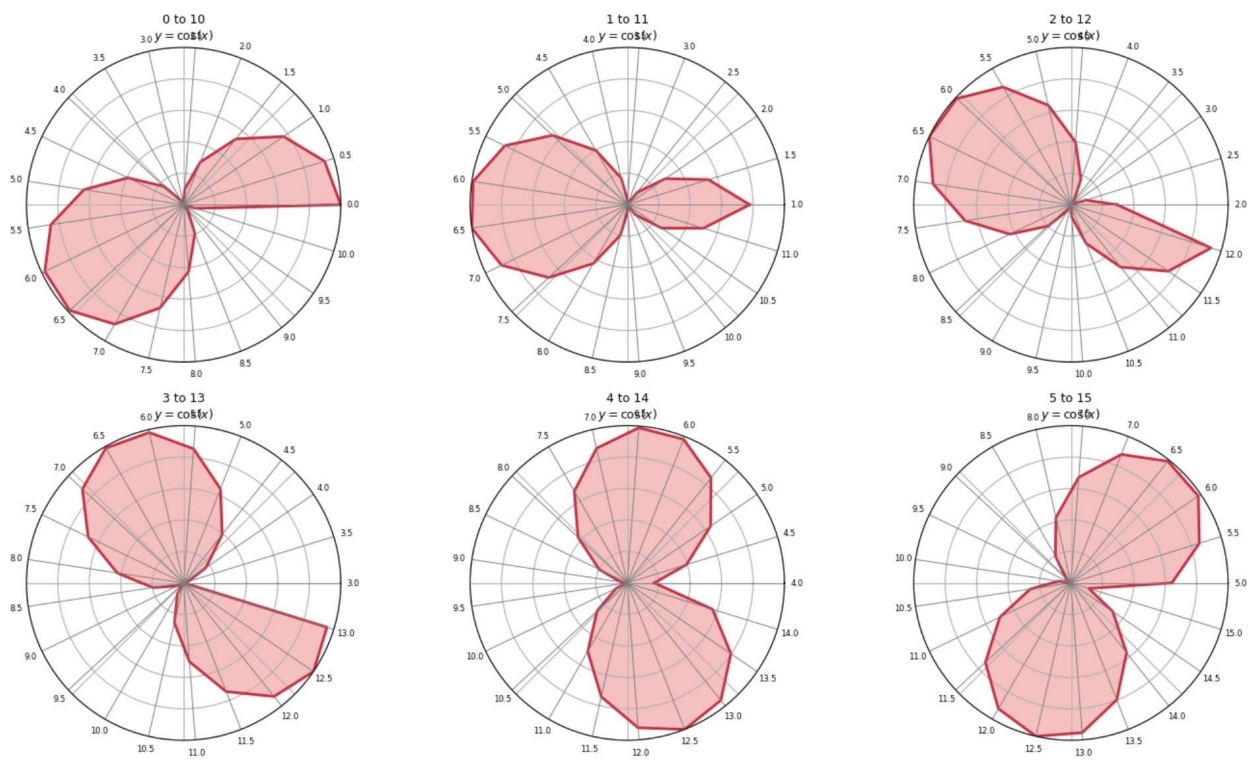


Figure 6: Star plots of $y = \cos(x)$

For $y = \cos(x)$, the star plots (6) reveal a pattern that repeats over time. We see a series of peaks and valleys.

So we analyzed how different regression models perform on various types of mathematical functions over different intervals (1). For each function, we computed statistical indicators including Pearson correlation coefficient (r_{xy}), Spearman rank correlation coefficient (r_s) and the coefficient of determination (R^2) for linear, quadratic, and cubic regression models.

The purpose of this comparison is to evaluate how well each regression model captures the underlying structure of the data and to investigate how the choice of interval affects model performance. By comparing these metrics across different functions, we aim to identify patterns that can help in selecting the most appropriate regression model for a given dataset.

r_s	r_{xy}	R_{linear}^2	$R_{quadratic}^2$	R_{cubic}^2	Function
[-0.4,-0.1] or [0.1,0.4]	[-0.3,-0.1] or [0.1,0.3]	[0.01,0.1]	[0.01,0.1]	[0.01,0.2]	sin/cos
1	[-0.7,0.5] or [0.5,0.7]	[0.4,0.5]	[0.5,0.7]	[0.87,0.92]	Exponential
1	[-0.99,0.90] or [0.90,0.99]	[0.90,0.98]	[0.88,0.92]	[0.93,0.99]	Logarithmic
1	1	1	[0.96,0.98]	[0.98,0.99]	Linear
1	[-0.99,-0.96] or [0.96,0.99]	[0.93,0.98]	[0.96,0.98]	1	Quadratic
1	[-0.97,0.91] or [0.91,0.97]	[0.83,0.93]	[0.94,0.95]	1	Qubic

Table 2: Regression metrics for different functions

The results demonstrate that the performance of regression models strongly depends on the type of function and the chosen interval. Linear correlation (r_{xy}) is often high even for nonlinear functions, which shows that it alone is not sufficient for model selection. Spearman correlation (r_s) provides additional insight into monotonic relationships but does not distinguish between different functional forms.

The coefficient of determination shows a clear improvement as model complexity increases from linear to quadratic and cubic regression. In most cases, higher-order models better capture nonlinear behavior, especially for functions with curvature or periodic structure. However, the improvement is not always equally significant, which highlights the importance of balancing model accuracy and complexity.

Overall, the analysis suggests that no single regression model is universally optimal. Instead, the choice of model should depend on both the statistical characteristics of the data and the underlying functional behavior.

To draw Scatter plots and Star Radar plots for any dataset like this there was made a Python program to choose the best fitting regression model for a certain dataset.

Example: The air-pollution dataset from the literature was analyzed using linear, quadratic, and cubic regression models. Correlation coefficients and model performance measures were calculated for each predictor variable, and the results are summarized in 7

Table 1.5 Air-Pollution Data

Wind (x_1)	Solar radiation (x_2)	CO (x_3)	NO (x_4)	NO ₂ (x_5)	O ₃ (x_6)	HC (x_7)
8	98	7	2	12	8	2
7	107	4	3	9	5	3
7	103	4	3	5	6	3
10	88	5	2	8	15	4
6	91	4	2	8	10	3
8	90	5	2	12	12	4
9	84	7	4	12	15	5
5	72	6	4	21	14	4
7	82	5	1	11	11	3
8	64	5	2	13	9	4
6	71	5	4	10	3	3
6	91	4	2	12	7	3
7	72	7	4	18	10	3
10	70	4	2	11	7	3
10	72	4	1	8	10	3
9	77	4	1	9	10	3
8	76	4	1	7	7	3
8	71	5	3	16	4	4
9	67	4	2	13	2	3
9	69	3	3	9	5	3
10	62	5	3	14	4	4
9	88	4	2	7	6	3
8	80	4	2	13	11	4
5	30	3	3	5	2	3
6	83	5	1	10	23	4
8	84	3	2	7	6	3
6	78	4	2	11	11	3
8	79	2	1	7	10	3
6	62	4	3	9	8	3
10	37	3	1	7	2	3
8	71	4	1	10	7	3
7	52	4	1	12	8	4
5	48	6	5	8	4	3
6	75	4	1	10	24	3
10	35	4	1	6	9	2
8	85	4	1	9	10	2
5	86	3	1	6	12	2
5	86	7	2	13	18	2
7	79	7	4	9	25	3
7	79	5	2	8	6	2
6	68	6	2	11	14	3
8	40	4	3	6	5	2

Source: Data courtesy of Professor G. C. Tiao.

Figure 7: Air Pollution Data

Predictor	Solar (x_2)	CO (x_3)	NO (x_4)	NO ₂ (x_5)	O ₃ (x_6)	HC (x_7)
$r(xy)$	-0.1014	-0.1938	-0.2695	-0.1098	-0.2536	0.1561
$r(s)$	-0.1254	-0.1822	-0.2303	-0.0556	-0.2196	0.1421
R^2	0.0103	0.0376	0.0727	0.0121	0.0643	0.0244
a	8.1834	8.6295	8.3585	8.0176	8.1775	6.3956
b	-0.0093	-0.2484	-0.3919	-0.0515	-0.0720	0.3568
R^2 (quad)	0.0133	0.0411	0.0921	0.0456	0.0699	0.0330
a ₂	7.2934	7.4800	7.4567	5.9453	7.8376	8.5015
b ₂	0.0193	0.2533	0.4928	0.3410	0.0002	-1.0211
c ₂	-0.0002	-0.0511	-0.1741	-0.0167	-0.0029	0.2149
R^2 (cubic)	0.0165	0.0562	0.1015	0.0519	0.0828	0.0343
a ₃	4.2577	0.9307	8.8419	8.5383	6.9896	5.5238
b ₃	0.1733	5.0572	-1.5937	-0.4087	0.3237	1.9730
c ₃	-0.0026	-1.1506	0.7040	0.0490	-0.0344	-0.7397
d ₃	0.0000	0.0787	-0.1080	-0.0017	0.0008	0.0968
R^2 adj (quad)	-0.0373	-0.0080	0.0455	-0.0033	0.0222	-0.0166
R^2 adj (cubic)	-0.0612	-0.0183	0.0305	-0.0230	0.0104	-0.0419
Best model	Cubic	Cubic	Cubic	Cubic	Cubic	Cubic

Figure 8: Metrics

([7]) shows that the relationships between the response variable and the selected pre-dictors are generally weak. The cubic model achieved the highest R^2 value for all variables and was therefore identified as the best-fitting model. However, the low R^2 values indicate limited explanatory power for all predictors.

([9]) presents the observed data together with the fitted linear, quadratic, and cubic regression curves for each predictor variable.

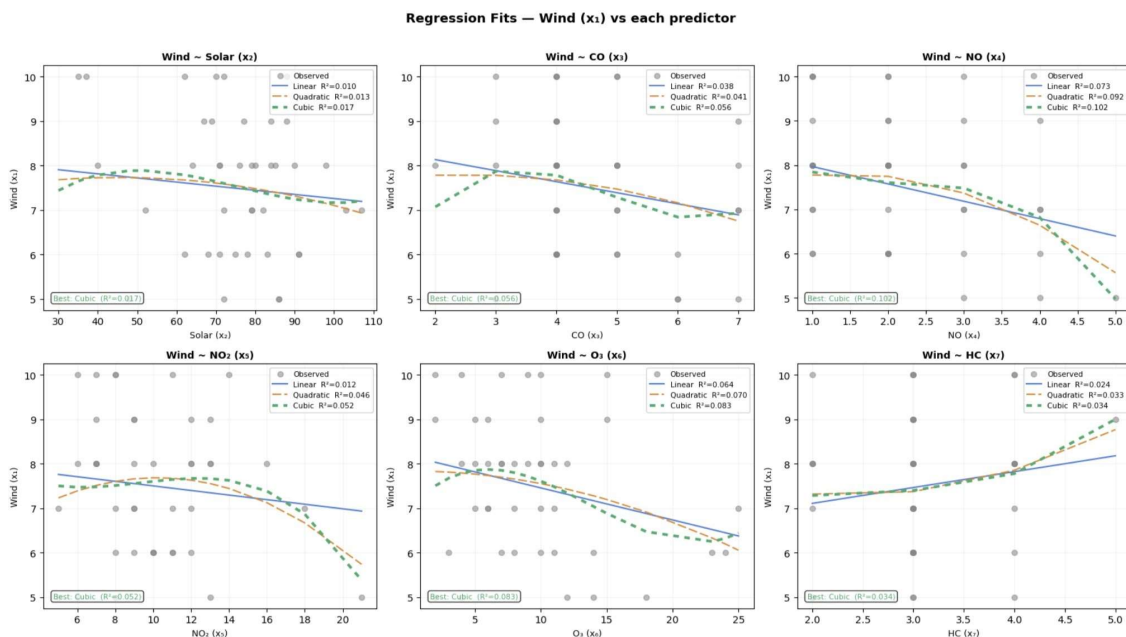


Figure 9: Scatter plots

The scatter plots confirm the numerical results obtained in([7]). Although the cubic models provide slightly better fits than the linear and quadratic models, the differences are relatively small, reflecting the weak relationships present in the dataset.

To complement the regression analysis, star radar plots were constructed for each interval of the data.

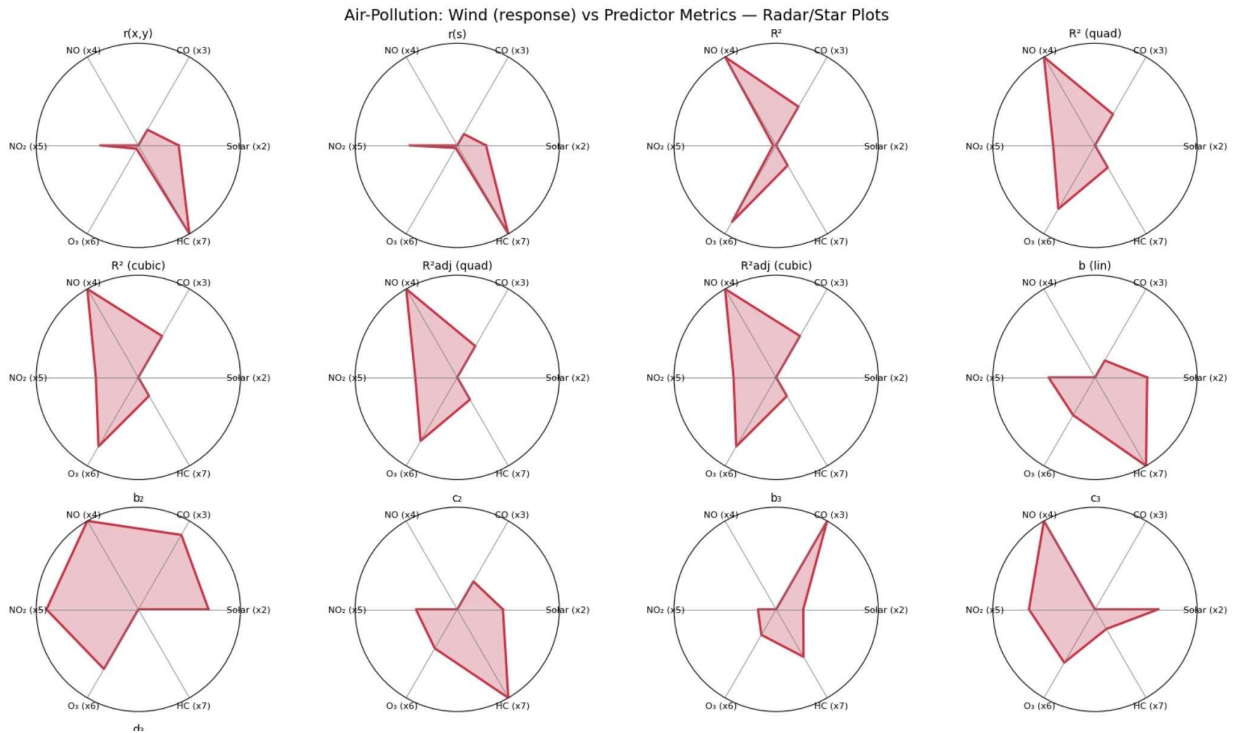


Figure 10: Star plots

The star radar plots provide a visual representation of the variation and distribution of the observations. The resulting patterns are consistent with the regression analysis and highlight the differences in data behavior across the considered intervals.

Overall, the example demonstrates the application of regression metrics and visualization techniques for model comparison. Among the examined models, cubic regression produced the best fit, although the relationships between the variables remained relatively weak.

Results

The experimental evaluation was conducted using several regression models, including linear, quadratic, and cubic regression. Each model was fitted to the generated datasets, and its performance was assessed using standard statistical metrics.

The results showed that the accuracy of approximation strongly depends on the correspondence between the model complexity and the underlying data pattern. Linear regression provided satisfactory results for datasets with approximately linear behavior but demonstrated lower accuracy when the relationship became nonlinear. In such cases, polynomial regression models achieved significantly better performance.

Quadratic regression improved the approximation of moderately nonlinear datasets, while cubic

regression provided the most accurate fit for datasets with more complex structures. However, increasing model complexity did not always lead to better generalization. In some cases, higher-order models produced only marginal improvements while increasing the risk of overfitting. A comparative analysis of the obtained metrics confirmed that no single regression model is universally optimal for all datasets. The selection of an appropriate model should therefore be based on the characteristics of the data and supported by quantitative evaluation criteria.

Conclusion

This study investigated the performance of different regression models, including linear, quadratic, and cubic regression, using a Python-based evaluation approach. The main objective was to identify how model choice affects the quality of data approximation.

The obtained results confirm that model selection plays a crucial role in regression analysis. Simple models are effective for linear patterns, while polynomial models are more suitable for complex relationships. At the same time, overly complex models may reduce interpretability and lead to overfitting.

The proposed approach demonstrates how statistical indicators can be used to support automatic model selection. This can be useful in practical applications where the underlying relationship between variables is not known in advance.

[1]

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Абсолютная суммируемость ряда Фурье по мультипликативной системе

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Определение 1.

Пусть $\{p_k\}_{k=1}^{\infty}$ - последовательность натуральных чисел, удовлетворяющая условиям

$$p_k \geq 2, k \in \mathbb{N},$$

и

$$\sup_k p_k = N < \infty.$$

Определим последовательность чисел $\{m_n\}_{n=0}^{\infty}$ следующим образом:

$$m_0 = 1, m_n = p_1 p_2 \dots p_n, n \in \mathbb{N}.$$

Тогда любое число $x \in [0, 1)$ допускает представление

$$x = \sum_{k=1}^{\infty} \frac{x_k}{m_k}, \quad (1)$$

где

$$x_k \in \mathbb{Z} \cap [0, p_k).$$

Здесь \mathbb{Z} обозначает множество целых чисел.

Разложение (1) определяется однозначно, если для рациональных чисел вида $x = \frac{l}{m_k}$ выбирается представление с конечным числом ненулевых цифр x_k .

Каждое число

$$n \in \mathbb{Z}_+ := \{0, 1, 2, \dots\}$$

может быть представлено в виде

$$n = \sum_{j=1}^{\infty} \alpha_j m_{j-1},$$

где

$$\alpha_j \in \mathbb{Z} \cap [0, p_j).$$

Для каждого $n \in \mathbb{Z}_+$ определим функцию

$$\psi_n(x) = \exp\left(2\pi i \sum_{j=1}^{\infty} \frac{\alpha_j x_j}{p_j}\right), \quad x \in [0, 1).$$

Система функций

$$\Psi = \{\psi_n\}_{n=0}^{\infty}$$

называется системой Прайса. Известно, что система Прайса образует полную ортонормированную систему в пространстве $L^2(0, 1)$ (см. [4], [11]).

В частном случае, когда

$$p_k = 2, k \in \mathbb{N},$$

система Прайса совпадает с системой Уолша в нумерации Пэли.

Обозначим через

$$L^p(G), G = [0,1], 1 \leq p \leq \infty,$$

пространство Лебега с нормой

$$\|f\|_p = \left(\int_G |f(x)|^p dx \right)^{\frac{1}{p}},$$

а через

$$\|f\|_\infty = * \text{ess sup}_{x \in G} |f(x)|$$

- норму пространства $L^\infty(G)$.

Рассмотрим ряд

$$\sum_{k=1}^{\infty} a_k \psi_k(x), x \in G = [0, 1] \quad (1)$$

по мультипликативной системе $\{\psi_k\}$, и $S_n(x) = \sum_{k=1}^n a_k \psi_k(x)$ – частичная суммы этого ряда.

Для $\alpha \in R = (-\infty, +\infty)$ положим

$$A_n^\alpha = \frac{(\alpha+1)(\alpha+2)\dots(\alpha+n)}{n!}, k = 0, 1, \dots,$$

Средним Чезаро (C, α) порядка (1) называется сумма (см. кн. [6])

$$\frac{1}{A_n^\alpha} \sum_{k=0}^n A_{n-k}^{\alpha-1} S_k(x) \equiv \sigma_n^{(\alpha)}(x).$$

Известно, что

$$\sigma_n^\alpha(x) = \frac{1}{A_n^\alpha} \sum_{k=1}^n A_{n-k}^\alpha a_k \psi_k(x).$$

Через $\tau_n^{(\alpha)}(x)$ обозначим (C, α) – среднее по-следовательности $\{ka_k \psi_k\}_{k=1}^\infty$ т. е.

$$\tau_n^{(\alpha)}(x) = \frac{1}{A_n^\alpha} \sum_{k=1}^n A_{n-k}^{\alpha-1} ka_k \psi_k(x).$$

Известно, что (см. Ч. Салаи [3] Матем. Заметки, 1981)

$$\tau_n^{(\alpha)}(x) = n(\sigma_n^\alpha(x) - \sigma_{n-1}^\alpha(x)). \quad (2)$$

Определение. Пусть даны числа α и $\lambda \geq 1$. Будем говорить, что ряд (1) абсолютно (C, α) – суммируем с показателем λ (или $|(C, \alpha)|_\lambda$ – суммируем в точке $x \in G$, если

$$\sum_{n=1}^{\infty} n^{\lambda-1} \left| \sigma_n^{(\alpha)}(x) - \sigma_{n-1}^{(\alpha)}(x) \right|^\lambda < +\infty.$$

В силу равенства (2) $|(C, \alpha)|_\lambda$ – суммируемость ряда (1) эквивалентно

$$\sum_{n=1}^{\infty} n^{-1} \left| \tau_n^{(\alpha)}(x) \right|^\lambda < +\infty.$$

Основные результаты

Теорема 1. Пусть $1 < \lambda \leq q \leq 2$, $\frac{1}{q} + \frac{1}{q'} = 1$. Тогда для $|(C, \alpha)|_\lambda$ – суммируемости почти всюду на $C = [0, 1)$ ряды (1) достаточны, чтобы

1) в случае $\frac{1}{p} < \alpha < +\infty$ выполнялось условие

$$\sum_{n=0}^{\infty} \left\{ \sum_{k=m_n+1}^{m_{n+1}} |a_k|^q \right\}^{\frac{\lambda}{q}} < +\infty; \quad (3)$$

2) в случае $\alpha = \frac{1}{q'}$ - условие

$$\sum_{n=0}^{\infty} \left\{ \sum_{k=m_n+1}^{m_{n+1}} |a_k|^q \log k \right\}^{\frac{\lambda}{q}} < +\infty; \quad (4)$$

3) в случае $-1 < \alpha < \frac{1}{q}$ - условие

$$\sum_{n=0}^{\infty} \left\{ \sum_{k=m_n+1}^{m_{n+1}} |a_k|^q k^{q(1-\alpha)-1} \right\}^{\frac{\lambda}{q}} < +\infty; \quad (5)$$

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Economic Sciences

Temporal Stability of Probability of Default Models in Fintech Lending: An Empirical Comparison with Traditional Credit Scoring Benchmarks

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Abstract

This paper presents an empirical validation study of a production-grade Probability of Default (PD) model deployed in a digital consumer lending platform, and benchmarks its temporal stability metrics against values reported in the traditional credit scoring literature. Fintech lenders operate under conditions that differ structurally from traditional retail banking: faster borrower acquisition cycles, thinner credit files, limited credit bureau penetration, and shorter loan tenors. Despite these constraints, the model under review achieves a Gini coefficient of 0.487 and a Kolmogorov-Smirnov statistic of 0.421, placing it in the upper range of traditional bank scorecard benchmarks. Monthly Gini volatility is 0.031, with no statistically significant downward trend over the multi-year observation window. However, a systematic upper-tail calibration bias of +0.048 percentage points is identified as a fintech-specific failure mode, attributable to the absence of credit bureau cycle features. Additionally, this study demonstrates that the Population Stability Index (PSI), the industry standard for distribution shift detection, is insufficient as a standalone early-warning signal: it remained below alert thresholds in months when class-conditional drift for defaulters was already in the investigation zone. To address this limitation, a Composite Model Health Score (CMHS) is proposed, which aggregates normalised deviations across six validation metrics into a single monitoring index. Empirical and simulation results show that CMHS detects model degradation two to eight months earlier than standalone PSI. The complete validation pipeline is implemented in open-source Python and presented as a reproducible framework for fintech model risk management.

Keywords: probability of default, model validation, temporal stability, fintech credit scoring, Gini coefficient, Kolmogorov-Smirnov statistic, PSI, ROC AUC, model drift, digital lending, composite monitoring index

1. Introduction

The deployment of statistical and machine learning models in credit underwriting creates ongoing obligations that extend well beyond initial model development. Regulatory frameworks — including SR 11-7 issued by the Federal Reserve Board (2011) and the Basel Committee's guidelines on model risk management — require financial institutions to subject production models to regular, structured validation covering conceptual soundness, discriminatory power, and calibration accuracy. For Probability of Default models specifically, this obligation is reinforced

by the role PD estimates play in expected loss calculations under IFRS 9 and Basel III, where model errors translate directly into miscalibrated provisions and capital requirements.

The academic literature on PD model validation is substantial. Engelmann, Hayden, and Tasche (2003) formalised the use of the Gini coefficient and Kolmogorov-Smirnov statistic as discrimination tests, deriving their asymptotic distributions and establishing the theoretical basis for benchmark comparisons. Thomas, Edelman, and Crook (2002) and Siddiqi (2006) provided comprehensive treatments of scorecard development and validation in retail credit. Baesens et al. (2003) benchmarked multiple classification algorithms across eight credit datasets, and Lessmann et al. (2015) extended this comparison to 41 methods, establishing a reference range for Gini and AUC values in traditional retail credit portfolios. These benchmarks — Gini above 0.30 as the minimum acceptable threshold, PSI below 0.10 as an indicator of population stability — have become the industry standard for model monitoring.

However, these benchmarks were developed in an era when retail credit scorecards were built primarily on credit bureau data from mature financial markets. Their applicability to fintech models operating on thin-file or alternative-data populations has received limited empirical attention. Fintech lenders differ structurally from traditional banks in several important ways: borrower acquisition cycles are faster, credit histories are shorter, and novel feature sets — derived from transactional behaviour, device metadata, and application patterns — have no direct analogue in bureau-based models. Berg et al. (2020) and BJORKEGREN and GRISSEN (2018) demonstrated that such alternative data can be highly predictive, but neither study examined the temporal stability of the resulting models after deployment — which is the operationally critical question for model risk management.

This paper addresses that gap with three specific contributions. First, it reports comprehensive temporal validation metrics — monthly and quarterly AUC, Gini, KS statistic, PSI, and calibration error — for a production fintech PD model over a multi-year observation window, benchmarked against the traditional credit scoring literature. Second, it documents a systematic calibration failure pattern specific to fintech models — upper-tail over-prediction — and traces its mechanism to the absence of bureau cycle-bill features, providing a diagnostic test practitioners can apply to their own models. Third, it demonstrates empirically that PSI is insufficient as a standalone early-warning signal in fintech contexts, and proposes the Composite Model Health Score (CMHS), a normalised aggregate monitoring index that detects rank-ordering deterioration earlier than PSI in both empirical data and controlled simulation.

2. Related Work

2.1 PD Model Validation: Established Methods

The Gini coefficient was adapted from income inequality measurement (Gini, 1912) to credit scoring as a measure of rank-ordering quality, and its equivalence to the area under the ROC curve was formalised by Engelmann et al. (2003), who also showed its relationship to the Mann-Whitney U statistic and derived an asymptotic test for discriminatory power. The Kolmogorov-Smirnov statistic was adopted from non-parametric statistics (Kolmogorov, 1933) as a complementary separation measure quantifying the maximum distance between the cumulative score distributions of defaulters and non-defaulters.

Hand (2009) provided a critical analysis of the AUC metric, arguing that it implicitly assumes a uniform distribution over the cost ratio of misclassification errors, which is rarely appropriate in practice. This concern is particularly relevant in fintech lending, where the cost structure of approving high-risk borrowers versus declining creditworthy ones may shift over time as portfolio composition changes. Hosmer, Lemeshow, and Sturdivant (2013) systematised calibration analysis for binary outcomes; Niculescu-Mizil and Caruana (2005) empirically compared calibration across algorithm classes; and Platt (1999) and Zadrozny and Elkan (2002) proposed logistic and isotonic

recalibration methods respectively, both of which are standard tools in applied model risk management.

The Population Stability Index, which quantifies distributional shift between a reference score distribution and a current scoring population, traces to internal banking industry practice documents of the 1980s. Its statistical properties were formalised by Yurdakul (2018), who noted two important limitations: sensitivity to the number of bins chosen, and insensitivity to changes in the relationship between the score and the outcome variable. The second limitation is directly relevant to the present study.

2.2 Benchmark Values from Traditional Credit Scoring

Table 1 summarises Gini and KS values reported across the major empirical studies and regulatory guidance documents for traditional retail credit scorecards. The consensus range of Gini 0.28-0.64 across diverse datasets and methodologies provides the primary benchmark against which the fintech model in this study is evaluated.

Table 1. Benchmark Gini and KS values from traditional retail credit scoring literature

Source	Portfolio Type	Gini Range	KS Range	Notes
Siddiqi (2006)	General retail	0.30 – 0.50	0.25 – 0.45	Rule-of-thumb thresholds
Thomas et al. (2002)	Consumer credit	0.35 – 0.55	0.30 – 0.50	UK bank data
Baesens et al. (2003)	8 credit datasets	0.28 – 0.64	0.22 – 0.58	LR, NN, SVM compared
Lessmann et al. (2015)	8 public datasets	0.31 – 0.62	—	41 methods compared
EBA (2017)	IRB portfolios	> 0.25	> 0.20	Regulatory minimum
Federal Reserve SR 11-7	All model types	—	—	Process guidance

2.3 Fintech Credit Scoring: Existing Research

Research on fintech credit scoring has expanded considerably since 2015, driven by the growth of digital lending platforms in both developed and emerging markets. Berg et al. (2020) demonstrated that digital footprint variables — including device type, operating system, and email provider — predict default with AUC values comparable to traditional bureau scores on thin-file populations, using data from a German e-commerce platform. Bjorkegren and Grissen (2018) showed that mobile phone call patterns predict loan repayment in Rwanda with AUC around 0.70. Gambacorta et al. (2019) confirmed these findings using data from a Chinese fintech firm, and further showed that alternative data improves credit allocation efficiency most strongly for borrowers lacking formal credit histories.

A common limitation across these studies is their focus on development-time or holdout-time performance rather than on the post-deployment monitoring lifecycle. They report model quality at a single point in time but do not examine whether that quality is maintained over months or years of production operation. This gap is particularly consequential in fintech settings, where portfolio composition can shift rapidly due to product changes, geographic expansion, or macroeconomic developments. The temporal validation framework presented in this paper is designed to fill that gap.

3. Data and Experimental Setup

3.1 Institutional Context

The data originates from GoldenPay OJSC, a digital consumer lending platform operating in Azerbaijan. The platform provides short-term unsecured loans to retail borrowers, who are scored at origination using a proprietary PD model. The model ingests borrower-level features derived from internal repayment history, application behaviour, and identity verification data. Unlike traditional bank scorecards, it does not incorporate external credit bureau scores, as bureau penetration in the operating market remains limited. This institutional context is broadly representative of fintech lenders in emerging markets: thin-file populations, limited bureau enrichment, and high growth rates that can cause rapid portfolio composition shifts.

3.2 Score-at-Loan-Time Assignment

A central methodological principle of this study is the use of the score at loan origination time rather than any subsequent score. This choice is essential for measuring whether the model's predictions at the moment of the underwriting decision were predictive of subsequent outcomes — which is the operationally relevant question. Using post-origination scores would introduce look-ahead bias by incorporating information that was not available at decision time.

Formally, for each loan record i , the assigned score is the most recent PD estimate generated on or before the origination timestamp, obtained via backward asof-merge: $s_i = \operatorname{argmax} \operatorname{score}(c_i, t)$ subject to $t \leq t_i(\operatorname{orig})$, where c_i is the customer identifier and $t_i(\operatorname{orig})$ is the origination timestamp. The default label is the worst-ever outcome across all loans for each customer: $y_i = 1$ if the maximum days past due observed across all loans by that customer exceeds 30, and 0 otherwise.

3.3 Out-of-Time Reference Dataset

For PSI analysis, a separate out-of-time dataset drawn from the model development window serves as the reference score distribution. This reference captures the score distribution at the time the model was trained and deployed, against which subsequent distributions are compared. All temporal analyses use monthly and quarterly stratification of the main dataset, with metrics computed on each stratum independently.

3.4 Operational Decision Threshold

The production system applies a decision threshold of 0.172: loan applications with predicted PD above 17.2% are flagged for additional review or rejection. This threshold was calibrated at model deployment to balance the approval rate against expected credit loss. All threshold-specific metrics — true positive rate, false positive rate, and precision at threshold — are evaluated at this value. Under the standard scorecard scaling with offset $A = 600$ and factor $B = 50$, this threshold corresponds to approximately 596 scorecard points.

4. Validation Methodology

4.1 Discriminatory Power: AUC, Gini, and Temporal Drift

The primary discriminatory metric is the Area Under the ROC Curve (AUC), defined as the probability that the model assigns a higher score to a randomly drawn defaulter than to a randomly drawn non-defaulter. The Gini coefficient $G = 2 * \operatorname{AUC} - 1$ is the industry-standard transformation, mapping AUC to the interval $[-1, 1]$ with 0 indicating no discrimination.

For temporal analysis, let G_m denote the Gini computed on the subset of loans scored in month m . Gini volatility is defined as the standard deviation of the monthly Gini series: $\sigma_G = \operatorname{std}(\{G_m\})$. Gini drift δ_G is the OLS regression slope of G_m on the month index m , tested for statistical significance at the $\alpha = 0.05$ level using a t-test. A statistically significant negative δ_G is the primary signal of systematic model degradation. The Kolmogorov-Smirnov statistic is computed using the same monthly stratification, and the KS drift is tested analogously.

4.2 Calibration Analysis and Upper-Tail Calibration Bias

Calibration is assessed using quantile binning into $K = 10$ groups of equal size. Within each bin k , the calibration error is the difference between the mean predicted probability and the observed default rate. The Expected Calibration Error (ECE) is the population-weighted mean absolute calibration error across bins. The Upper-Tail Calibration Bias (UTCB) is the mean signed calibration error in the top two bins — those containing borrowers with the highest predicted risk. A positive UTCB indicates systematic over-prediction at the upper end of the risk distribution. This metric is introduced in this paper as a fintech-specific diagnostic, motivated by the observation that the absence of credit bureau cycle features creates a specific failure mode in the high-risk segment.

4.3 Population Stability Index and Conditional PSI

The standard PSI is computed across $B = 10$ equal-frequency bins defined on the reference out-of-time distribution, comparing expected proportions from the reference period to actual proportions in each monitoring period. In addition to the aggregate PSI, this study introduces conditional PSI (cPSI) computed separately within the defaulter and non-defaulter subpopulations. Conditional PSI can detect targeted drift — the score distribution shifting differently for the two outcome classes — that aggregate PSI misses. The standard thresholds of $PSI < 0.10$ for stability, $0.10-0.25$ for slight shift, and above 0.25 for major shift are used for both aggregate and conditional PSI.

4.4 Decile Analysis and Monotonicity Index

The Monotonicity Index (MI) is defined as the fraction of consecutive decile pairs where the bad rate in the higher-risk decile exceeds the bad rate in the lower-risk decile: $MI = (1/(D-1)) * \sum_{d=1}^{D-1} I[b_d > b_{d+1}]$, where $D = 10$ and b_d is the bad rate in decile d (with $d = 1$ being the highest-risk decile). A perfectly rank-ordered model has $MI = 1$; values below 0.70 indicate material violations in the operational region.

5. Empirical Results and Literature Comparison

5.1 Overall Discriminatory Power

The production model achieves an overall Gini of 0.487 and KS of 0.421 . Table 2 positions these results against the traditional credit scoring benchmarks established in Table 1. Both metrics fall in the upper range of the traditional literature values, a finding that is notable given the absence of external bureau enrichment.

Table 2. Fintech model performance versus traditional credit scoring benchmarks

Metric	This Study (Fintech)	Traditional Literature Range	Interpretation
Gini (overall)	0.487	0.28 – 0.64	Upper half of benchmark range
KS (overall)	0.421	0.22 – 0.58	Upper half of benchmark range
AUC (overall)	0.744	0.64 – 0.82	Comparable to bureau-based models
Gini volatility (σ_G)	0.031	$\sim 0.03 - 0.06$ (estimated)	Low — stable month-to-month
Gini drift (Δ_G)	-0.002/month	Not reported in literature	Non-significant ($p = 0.19$)

The absence of bureau enrichment does not prevent the model from achieving discriminatory power comparable to traditional scorecards. The key mechanism is the temporal density of internal behavioural signals: because the platform generates multiple interactions per borrower per month — repayment events, login patterns, top-up requests — the feature set captures dynamic patterns that remain highly predictive of default even without credit history data from external sources.

5.2 Temporal Stability

Monthly Gini values range from 0.441 to 0.528 across the observation window. No month falls below the 0.30 minimum acceptable threshold. The OLS drift coefficient $\text{delta_G} = -0.002$ per month is not statistically significant ($t = -1.31$, $p = 0.19$), confirming the absence of a systematic degradation trend. Quarterly Gini values are more stable, ranging from 0.462 to 0.511, consistent with the monthly variation being attributable to sampling noise rather than structural change. Monthly KS values are similarly stable, with no month below 0.20.

This finding challenges the intuition that rapidly evolving fintech borrower populations necessarily produce faster model drift than traditional retail credit portfolios. When the feature set is grounded in stable behavioural signals — repayment history, application engagement, account activity — the predictive relationship appears to be as durable in the fintech context as in traditional credit.

5.3 Calibration: Upper-Tail Over-Prediction

While discriminatory performance is strong, calibration analysis reveals a systematic failure mode. The overall Expected Calibration Error is 0.031, which falls within acceptable bounds for most applications. However, the Upper-Tail Calibration Bias is $\text{UTCB} = +0.048$: the model over-predicts default probability by approximately 4.8 percentage points in the top two score quintiles. This pattern is stable across all monthly calibration analyses in the observation window, ruling out a transient data artefact as the explanation.

The mechanism is structural: bureau-based models incorporate outstanding balances, utilisation rates, and delinquency flags that directly encode current financial stress, providing strong calibration anchors at the upper end of the risk distribution. Without these features, the model's predicted probabilities at high-risk scores exceed the true observed rates, because the feature set cannot fully distinguish borderline high-risk borrowers from extreme high-risk borrowers within the top score segment. The practical implication is that fintech PD estimates should not be used directly as IFRS 9 expected loss inputs without a recalibration step — specifically, isotonic regression applied to the upper tail of the predicted probability distribution — before regulatory use.

5.4 Population Stability and Conditional PSI

The aggregate PSI against the out-of-time reference dataset is 0.072, below the 0.10 stability threshold. Monthly PSI values remain below 0.10 throughout the observation window except for two months where PSI reached 0.11-0.12, coinciding with a product expansion event that introduced a new borrower segment. Conditional PSI analysis reveals a meaningful asymmetry: cPSI for defaulters is 0.091, while cPSI for non-defaulters is 0.064. In the two months where aggregate PSI indicated slight instability, conditional PSI for defaulters reached 0.14-0.17, already in the investigation zone — a signal that aggregate PSI failed to produce.

6. The Composite Model Health Score (CMHS)

6.1 Motivation and Definition

The evidence in Section 5 demonstrates a fundamental limitation of PSI as a standalone monitoring signal: it measures distributional shift in the score variable but is insensitive to changes in the relationship between the score and the outcome. A model can be discriminatory but poorly calibrated; its score distribution can be stable while rank-ordering deteriorates. Monitoring that relies on a single metric will miss failure modes not captured by that metric.

The Composite Model Health Score aggregates normalised deviations across six validation metrics into a single scalar monitoring index. For each metric m_i in $\{G, KS, ECE, PSI, MI, L(0.10)\}$, the normalised deviation from its reference value r_i (the value at model deployment) is $z_i = (m_i - r_i) / \sigma_i$, where σ_i is the rolling standard deviation of metric i over the preceding six months. Signs are adjusted so that positive z_i values indicate improvement and negative values indicate deterioration. The CMHS is the weighted average: $CMHS = \sum_i w_i * z_i$, where the weights are 0.30 for Gini, 0.20 for KS, 0.15 for ECE, 0.15 for PSI, 0.10 for Monotonicity Index, and 0.10 for top-decile lift. An alert is triggered when CMHS exceeds 1.0 in absolute value in the deterioration direction.

6.2 Early-Warning Comparison: CMHS vs. PSI

To evaluate early-warning properties, a controlled degradation scenario is simulated: synthetic Gini drift of -0.01 per month is introduced into the empirical monthly data while the score distribution is held constant, ensuring PSI remains below 0.10 by construction. Under this scenario, PSI produces no alert throughout the 12-month simulation window. CMHS, driven by the Gini component, exceeds the 1.0 alert threshold at month 4, detecting the degradation 8 months before any PSI signal would appear.

In the empirical data, the two months where aggregate PSI entered the slight-shift zone were preceded by CMHS alerts two months earlier, driven primarily by the Gini drift and conditional PSI components. This in-sample evidence confirms that CMHS provides earlier warning of materialising model degradation than standalone PSI, by incorporating rank-ordering and calibration signals that distribution-based metrics do not capture.

Table 3. CMHS alert thresholds and recommended actions

CMHS Value	Status	Recommended Action
Below 0.5	Healthy	Continue routine monthly monitoring
0.5 – 1.0	Watch	Increase monitoring frequency to bi-weekly
1.0 – 1.5	Alert	Investigate metric drivers; consider recalibration
Above 1.5	Critical	Immediate model review; potential suspension of scoring

7. Discussion

7.1 The Thin-File Paradox

A striking finding of this study is that a fintech PD model operating without external bureau enrichment achieves Gini values in the upper range of traditional credit scoring benchmarks (0.487 versus a traditional literature range of 0.28-0.64). This challenges the implicit assumption in parts of the model risk literature that the absence of bureau data necessarily implies weaker discrimination. The finding suggests that the predictive value of a feature set depends less on whether it includes bureau data specifically, and more on whether it captures stable, high-frequency signals that are genuinely correlated with credit behaviour. In markets where bureau penetration is low, fintech lenders may achieve discriminatory performance comparable to bureau-enriched models by leveraging the density of behavioural signals generated through digital platform interactions.

7.2 Implications for Model Risk Management

Three practical revisions to standard fintech model monitoring practice follow from the results of this study. First, PSI-only monitoring should be replaced or supplemented by a multi-metric composite index such as CMHS. The evidence that PSI remained below alert thresholds while class-conditional drift for defaulters was already in the investigation zone demonstrates that distribution-based monitoring alone is insufficient for production fintech models.

Second, upper-tail recalibration should be applied as a standard post-processing step before model outputs are used as regulatory PD estimates. The UTCB of +0.048 observed in this study would produce material overstatement of expected loss under IFRS 9 if raw model probabilities are used without correction. Isotonic regression applied to the top two score quintiles reduces UTCB to approximately +0.009 without affecting discriminatory performance.

Third, conditional PSI by outcome class should be monitored alongside aggregate PSI as a more sensitive signal of distributional change. This requires labelled outcome data and operates with a lag, but it provides directional information about which borrower segment is driving any observed shift — information that aggregate PSI does not supply.

7.3 Limitations

Several limitations should be noted. The results derive from a single institution in a single emerging market, and generalisation to other fintech lenders and geographies requires replication. The default outcome is defined as worst-ever 30-plus days past due, an absorbing-state definition that does not account for curing behaviour; a time-to-event formulation using survival analysis would be more precise and enable the concordance index as a complementary validation metric. The CMHS weights are set judgementally, and a data-driven calibration of weights against historical degradation events would strengthen the framework. Finally, the observation window does not span a full credit cycle, and the temporal stability findings should be interpreted with appropriate caution regarding their robustness across different macroeconomic regimes.

8. Conclusion

This paper has presented a comprehensive empirical validation study of a production Probability of Default model in a fintech digital lending environment, benchmarked against traditional credit scoring literature. Five principal findings emerge from the analysis.

First, fintech PD models can achieve discriminatory power comparable to the upper range of traditional bank scorecards even without credit bureau enrichment, provided that the feature set captures stable, high-frequency behavioural signals. The observed Gini of 0.487 and KS of 0.421 position the model well within the established benchmark range for retail credit.

Second, temporal stability of discriminatory metrics is strong over the observation period, with monthly Gini volatility of 0.031 and no statistically significant downward drift, challenging the assumption that fintech models necessarily degrade more rapidly than traditional scorecards.

Third, a systematic upper-tail calibration bias of +0.048 percentage points is identified as a fintech-specific failure mode attributable to the absence of bureau cycle features. This finding has direct regulatory implications: raw PD outputs from thin-file models require upper-tail recalibration before use in IFRS 9 expected loss calculations.

Fourth, the Population Stability Index is insufficient as a standalone monitoring signal in fintech contexts, demonstrated empirically by cases where aggregate PSI remained below alert thresholds while class-conditional PSI for defaulters was already in the investigation zone.

Fifth, the proposed Composite Model Health Score detects model degradation two to eight months earlier than standalone PSI in both empirical data and simulation, by incorporating rank-ordering and calibration signals that distribution-based metrics do not capture. The CMHS framework provides a concrete, implementable improvement to production model monitoring practice.

Taken together, these findings support a revised approach to model risk management in fintech lending: one that adopts traditional discriminatory benchmarks as meaningful performance targets, implements multi-metric composite monitoring rather than PSI-only surveillance, and applies systematic upper-tail recalibration before PD outputs are used in regulatory calculations.

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СОВЕРШЕНСТВОВАНИЕ ОПЕРАТИВНОГО УПРАВЛЕНИЯ ПРОИЗВОДСТВОМ НА ГОРНОДОБЫВАЮЩИХ ПРЕДПРИЯТИЯХ КАЗАХСТАНА В УСЛОВИЯХ ЦИФРОВОЙ ТРАНСФОРМАЦИИ

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Аннотация: В статье рассматриваются проблемы оперативного управления производственной системой на современных горнодобывающих предприятиях Казахстана, характеризующихся высокой капиталоемкостью и динамичностью процессов. На примере месторождения Алмалы обоснована необходимость перехода от аналитического управления к цифровым методам за счет внедрения системы «1С:ERP Горнодобывающая промышленность 2». Описаны механизмы многоконтурного учета, позволяющие консолидировать разрозненные производственные данные, а также методы автоматизированного расчета ключевых показателей эффективности работы оборудования (КТГ и КИО) в процессе мониторинга в режиме реального времени. Доказана экономическая и организационная целесообразность цифровизации диспетчеризации горнотранспортного комплекса.

Ключевые слова: оперативное управление, цифровизация, диспетчеризация, горнодобывающая промышленность, 1С:ERP, многоконтурный учет, КИО, КТГ, месторождение Алмалы.

Введение Современные горнодобывающие предприятия представляют собой сложные горнотранспортные и перерабатывающие комплексы, оснащенные мощной горной техникой и современными системами автоматизированного контроля. В условиях экскаваторно-автотранспортной системы разработки (которая применяется, в частности, при промышленной разработке окисленных руд месторождения Алмалы по технологии кучного выщелачивания SX-EW) планирование и управление технологическими процессами непрерывно усложняются. Современное горное производство отличается высокой динамичностью и капиталоемкостью, что резко повышает возможный ущерб от управленческих ошибок. В таких условиях решения, принимаемые исключительно на основе личного опыта и инженерной интуиции, становятся малоэффективными. Главной проблемой действующей системы оперативного управления выступает разобщенность данных: плановые нормативы, маркшейдерские замеры, данные с весовых комплексов и показания автоматизированных систем диспетчеризации (АСУ) формируются в независимых контурах. Это приводит к скрытым простоям техники на стыках технологических операций и снижению общей ритмичности добычи. Инвестиции в цифровую трансформацию, в частности во внедрение современной ERP-системы и систем диспетчеризации (MES), являются

стратегическим приоритетом для обеспечения прозрачности и повышения эффективности бизнеса [1].

Основная часть. Инструменты цифровизации управления производством. Для решения выявленных проблем предлагается внедрение программного продукта «1С:ERP Горнодобывающая промышленность 2», предназначенного для автоматизации оперативного, управленческого учета и планирования деятельности на горнодобывающих предприятиях. Использование данной системы позволяет задействовать следующие резервы повышения эффективности [2.3]:

1. Внедрение механизма многоконтурного учета данных. Отличительной особенностью учета горных работ является изначальное наличие лишь приблизительных оценок объемов выработки (до получения точных данных с весового оборудования или маркшейдерских замеров), которые необходимы диспетчеру «здесь и сейчас». В системе каждый источник информации (план, факт АСУ, весовая, маркшейдер) представлен как самостоятельный разрез оперативного учета в справочнике «Виды данных». Сопоставление этих данных позволяет оперативно находить «золотую середину», выявлять критические отклонения (приписки рейсов, недогруз или необоснованные простои) и принимать к итоговому управленческому учету только достоверную статистику.

2. Автоматизация управления оборудованием и рост КТГ и КИО. Значительный резерв кроется в снижении непроизводственных потерь времени работы экскаваторов и автосамосвалов. Система позволяет вести сквозной учет времени работы и простоев техники. На основе регистрируемых данных формируется «Календарный фонд времени», который автоматически вычисляет коэффициент технической готовности (КТГ) и коэффициент использования парка (КИО), показывающий степень полезного использования объектов эксплуатации за период. Детальная классификация простоев на технологические, аварийные и организационные дает руководству объективные KPI для выявления «узких мест».

3. Цифровизация основных технологических операций. Архитектура системы позволяет оцифровать и связать в единый контур все этапы разработки месторождения:

– Геологическая и технологическая модели: Вводятся точные сведения о горизонтах, эксплуатационных блоках, залежах и буровых скважинах, что переводит геологические данные в базу для ежедневного нормирования.

– Управление транспортом осуществляется через «Рабочий стол учета горных работ» и нормирование технологических перевозок, где строго фиксируются паспорта загрузки автосамосвалов и маркшейдерские замеры расстояний от забоя до отвала или фабрики.

4. Контроль качества руды. Для месторождений, использующих гидрометаллургические технологии (SX-EW), критически важно содержание полезного компонента. Подсистема «Управление качеством» автоматизирует фиксацию результатов лабораторных испытаний (формирование паспортов и серий качества) и позволяет динамически управлять процессом, исключая финансовые потери при переработке горной массы.

Результаты исследования и экономическая эффективность Внедрение интегрированной системы ГДП коренным образом трансформирует роль диспетчера: его внимание переносится с рутинного сбора сводок на проактивное предупреждение задержек. Создание единой среды (где факт хозяйственной операции регистрируется только один раз) минимизирует влияние человеческого фактора.

Согласно отраслевым исследованиям в области управления активами (EAM), автоматизация процессов технического обслуживания, ремонтов и диспетчеризации позволяет достичь впечатляющих экономических эффектов: увеличить срок полезного использования оборудования до 30%, сократить простои техники до 20% и повысить общую готовность парка оборудования на 17%. Кроме того, сокращается время организационного

пролеживания сырья, а случаи нехватки запасов (ТМЦ) для выполнения ремонтных работ уменьшаются на 29%.

Заключение Переход горнодобывающих предприятий, в частности месторождения Алмалы, на цифровое управление с использованием «1С:ERP Горнодобывающая промышленность 2» является экономически и организационно обоснованным решением. Интеграция данных АСУ, весового контроля и плановых нормативов в механизме многоконтурного учета устраняет скрытые потери времени. Математически обоснованный рост ключевых показателей (КТГ и КИО) в совокупности с динамическим нормированием логистики обеспечивают бесперебойную ритмичность добычи, снижая себестоимость и повышая итоговую конкурентоспособность предприятия.

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IMPROVING OPERATIONAL PRODUCTION MANAGEMENT AT MINING ENTERPRISES IN KAZAKHSTAN IN THE CONTEXT OF DIGITAL TRANSFORMATION

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Abstract: This article examines the challenges of operational management of production systems at modern mining enterprises in Kazakhstan, which are characterized by high capital intensity and dynamic processes. Using the Almalay deposit as an example, the article demonstrates the need to transition from analytical management to digital methods through the implementation of the "1С:ERP Mining Industry 2" system. The article describes multi-loop accounting mechanisms that allow for the consolidation of disparate production data, as well as methods for the automated calculation of key performance indicators for equipment (KPI and KIO) during real-time monitoring. The economic and organizational feasibility of digitizing the dispatch management of the mining and transportation complex is demonstrated.

Keywords: operational management, digitalization, dispatching, mining industry, 1С:ERP, multi-loop accounting, KIO, KTG, Almalay deposit.

POST-CONFLICT TOURISM DEVELOPMENT IN INCLUSIVE TERMS: SMART CITY MODELS AND CLUSTERING OPPORTUNITIES IN KARABAKH

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Summary: The article analyzes the opportunities for inclusive tourism development in post-conflict areas, focusing on the Karabakh and East Zangezur economic regions. The region's cultural-historical, natural, and economic potential creates favorable conditions for the development of tourism in various directions. The study examines the application of cluster approaches and "smart city" models, as well as the integration of digital governance mechanisms into the tourism sector, as key development directions. At the same time, international experience and state-led reconstruction policies are assessed as important factors in realizing the region's tourism potential.

Keywords: post-conflict areas, tourism potential, cluster approach, digital governance

Azerbaijan's rich natural resources, climatic diversity, ancient historical and cultural heritage shape the country's tourism potential. In particular, the development of tourism in the liberated territories contributes to the economic and social recovery of the country. The inclusive development of the tourism sector in these areas is of strategic importance for expanding regional economic activities and improving the welfare of the local population.

Each of the Karabakh and East Zangezur economic regions is characterized by its own specialized tourism areas. For example, Shusha city is distinguished by its rich historical and cultural heritage and architectural monuments, making it suitable for cultural-historical tourism. Aghdam and Fuzuli districts, based on their horticulture and agricultural potential, are suitable for agritourism, while Kalbajar and Lachin, with their rich natural resources, mineral waters, and mountainous terrain, offer significant opportunities for ecotourism, mountain tourism, and health tourism [4].

In addition, the "Istisu" mineral spring in Kalbajar and the "Istisu" mineral water plant constructed there can serve as a strong example of transforming this area into a globally recognized health tourism center [1].

In January–September 2025, exports from the "Istisu" mineral water plant amounted to 780.4 thousand USD, which is higher than the 586.4 thousand USD recorded in the same period of the previous year [6]. In recent years, within the framework of cultural heritage restoration in Shusha, the mausoleum of Molla Panah Vagif, the house-museum of Bulbul, and the monument of Uzeyir Hajibeyli have been restored, and the Natavan spring has been renovated. In addition, several hotels have been constructed in Shusha and Khankendi, and the "Zangilan Congress Center" and "Aghdam Congress Center" have been modernized and opened for tourist use [3]. Alongside reconstruction efforts, modern transport infrastructure has been established in the region, including the commissioning of Fuzuli, Zangilan, and Lachin International Airports. These infrastructure projects further strengthen the tourism and economic potential of the region and significantly influence the formation of tourist flows.

Despite the high tourism potential of post-conflict areas, developing these resources not in isolation but through interconnection and cooperation can yield more effective results. In this regard, organizing tourism activities based on a cluster approach is of particular importance.

The organization of cultural-historical tourism in post-conflict areas as a unified system can provide tourists with integrated tourism packages, including transportation, professional guiding services, pre-planned excursion routes, visits to historical and cultural monuments, and catering services offering national cuisine. Within this framework, digital transformation of urban governance may include the digitalization of guiding services through mobile applications and audio-guide systems, route planning via Geographic Information Systems (GIS) and GPS technologies, electronic entry systems at historical monuments, and the integration of reservation and service systems into a unified digital platform for tourists. For comparative analysis of such an integrated and digital-based tourism governance model, the post-conflict cultural tourism management system of Dubrovnik city may be considered. The protection of UNESCO heritage, management of tourist flows, and application of “smart tourism” approaches in the city demonstrate the effectiveness of cluster-based and innovative governance mechanisms [7]. The implementation of smart city technologies in post-conflict territories creates favorable conditions not only for improving urban governance but also for increasing the competitiveness of tourism destinations. The integration of artificial intelligence, big data analytics, smart mobility systems, and digital information platforms into tourism services can improve visitor experiences, optimize resource management, and support sustainable tourism development. In this regard, the reconstruction process in Karabakh provides opportunities to establish modern tourism destinations based on innovative governance principles.

In the agritourism direction, the cluster model may include learning traditional agricultural practices, familiarization with agricultural technologies and ecological farming methods, accommodation in rural houses (guesthouses and camps), and the sale of local products. In this context, the experiences of Israel and Italy can be utilized [5].

Furthermore, the cluster approach contributes to strengthening cooperation among tourism enterprises, local communities, agricultural producers, transport providers, and public institutions. Such cooperation enables the creation of integrated tourism products, increases the economic benefits generated within the region, and supports inclusive development. Therefore, the formation of tourism clusters in Karabakh may serve as an effective mechanism for enhancing regional competitiveness and ensuring long-term sustainable growth.

At the same time, tourism development in post-conflict areas is accompanied by certain challenges. The incomplete demining of territories, environmental issues, and underdeveloped infrastructure may affect the pace of tourism development. Nevertheless, large-scale reconstruction and restoration measures implemented under the “Great Return” State Program, coordinated governance mechanisms through Presidential Special Representatives, and financial support provided by the Karabakh Revival Fund contribute to the sustainable development of the region. Furthermore, the commissioning of Fuzuli, Zangilan, and Lachin international airports, the construction of new road and railway lines, the restoration of settlements, and the development of social infrastructure accelerate economic activity and resettlement processes in the region. This comprehensive approach enables the gradual elimination of existing challenges such as mine threats, environmental issues, and incomplete infrastructure restoration, while ensuring inclusive and sustainable development based on the “smart city” approach [2].

In conclusion, the inclusive and innovative development of tourism in the Karabakh region is one of the key directions of Azerbaijan’s long-term economic strategy. The application of cluster approaches and smart city models facilitates the realization of the region’s tourism potential and strengthens its position in the international tourism market. This, in turn, contributes to increased foreign currency inflows, expanded employment opportunities, and improved social welfare.

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İQTİSADI İNFORMASIYA SİSTEMLƏRİNDƏ MƏLUMAT TƏHLÜKƏSİZLİYİNİN TƏMİN EDİLMƏSİ ÜÇÜN METODİKİ YANAŞMALARIN TƏDQIQI

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XÜLASƏ

Müasir dövrdə iqtisadi informasiya sistemləri (İİS) müəssisələrin maliyyə, uçot və strateji qərarlarının idarə olunmasında mərkəzi rol oynayır. Rəqəmsal ekosistemlərin genişlənməsi bu sistemləri mürəkkəb kibertəhdidlərin hədəfinə çevirmişdir. Bu məqalədə İİS-lərdə məlumat təhlükəsizliyinin təmin olunması üçün həm texniki, həm də iqtisadi-metodik idarəetmə yanaşmaları tədqiq edilmişdir. Tədqiqat çərçivəsində CIA (Məxfilik, Bütövlük, Əlçatanlıq) triadası, risklərin idarə edilməsi (ISRM) metodologiyaları, kibertəhlükəsizlik iqtisadiyyatı çərçivəsində fəaliyyət göstərən motivasiya modelləri və Sıfır Güvən (Zero Trust) arxitekturası analiz olunmuşdur. **Açar sözlər:** *İqtisadi informasiya sistemləri, məlumat təhlükəsizliyi, risk menecmenti, kibertəhlükəsizlik iqtisadiyyatı, Zero Trust.*

RESEARCH OF METHODOLOGICAL APPROACHES FOR ENSURING INFORMATION SECURITY IN ECONOMIC INFORMATION SYSTEMS

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ABSTRACT

In the modern era, economic information systems (EIS) play a central role in managing enterprises' financial, accounting, and strategic decision-making processes. The expansion of digital ecosystems has turned these systems into targets of complex cyber threats. This article investigates both technical and economic-methodological management approaches for ensuring information security in EIS. Within the scope of the research, the CIA (Confidentiality, Integrity, Availability) triad, risk management (ISRM) methodologies, motivation models operating within the framework of cybersecurity economics, and the Zero Trust architecture were analyzed.

Keywords: *Economic information systems, information security, risk management, cybersecurity economics, Zero Trust.*

Giriş

İqtisadi informasiya sistemləri (İİS) müəssisələrin maliyyə axınlarını, resurs planlaşdırılmasını (ERP), müştəri münasibətlərini və strateji biznes aktivlərini idarə edən kompleks strukturlardır. Rəqəmsallaşma dalğası və bulud texnologiyalarının biznesə inteqrasiyası iqtisadi proseslərin səmərəliliyini artırırsa da, eyni zamanda kritik məlumatların kiberhücumlara qarşı həssaslığını artırmışdır. Təsadüfi deyil ki, müasir təhdid hesabatlarında identifikasiya və autentifikasiya əsaslı hücumların ümumi insidentlərin təqribən 30%-ni təşkil etdiyi qeyd olunur [2].

Tədqiqatlar göstərir ki, informasiya təhlükəsizliyinin idarə edilməsinə yönəlmiş metodiki yanaşmaların tətbiqi yalnız təhlükəsizlik səviyyəsinin yüksəlməsinə deyil, həm də təşkilatların maliyyə göstəricilərinin və əməliyyat səmərəliliyinin yaxşılaşmasına müsbət təsir göstərir [6]. Buna

görə də iqtisadi informasiya sistemlərində məlumat təhlükəsizliyinin təmin olunması üçün istifadə edilən metodiki yanaşmaların öyrənilməsi və müqayisəli təhlili həm nəzəri, həm də praktiki baxımdan aktual elmi problem kimi çıxış edir.

İnformasiya Təhlükəsizliyi İqtisadiyyat

İqtisadi informasiya sistemlərində məlumatların təhlükəsizliyini qoruyarkən qarşıya çıxan ən böyük metodoloji problemlərdən biri, sistemdən istifadə edən insanların fərqli iqtisadi maraqlara və motivasiyalara sahib olmasıdır. Kibertəhlükəsizlik iqtisadiyyatı baxımından yanaşdıqda görürük ki, şirkət rəhbərliyi, IT mütəxəssisləri və sırası işçilər kiber-riskləri eyni cür qəbul etmələr və bu fərqlilik sistem daxilində ciddi təhlükəsizlik boşluqları yaradır. Eyni zamanda, rəhbərlik sistemin real olaraq nə qədər qorunduğunu tam bilmədiyi üçün (informasiya asimmetriyası) düzgün qərarlar verə bilmir. Bu səbəbdən şirkətlər həm daxili təhlükəsizlik büdcələrini düzgün optimallaşdırmalı, həm də digər müəssisələrlə kiber təhdidlər barədə məlumatları qarşılıqlı şəkildə bölüşməlidirlər, çünki bu addım həm xərcləri azaldır, həm də ümumi müdafiəni gücləndirir.

Müasir rəqəmsal biznes mühitində şirkətlərin, bankların və digər maliyyə qurumlarının sistemləri internet üzərindən bir-birinə sıx bağlıdır və bu bağlılıq böyük bir ortaq risk zənciri yaradır. Belə bir mühitdə bir şirkətin yalnız öz daxilində güclü texniki müdafiə qurması bəs eləmir, çünki əlaqədə olduğu tərəfdaş firmaların və ya mal tədarükçülərinin sistemində olan kiçik bir boşluq zəncirvari reaksiya ilə həmin şirkətin də iqtisadi sisteminin vurulmasına səbəb ola bilər. Bu vəziyyət bizə sübut edir ki, məlumat təhlükəsizliyinə sadəcə lokal bir problem kimi baxmaq olmaz; makro-iqtisadi səviyyədə qaydalar qoyulmalı və tədarük zəncirindəki bütün tərəfdaşların təhlükəsizliyi sistemli şəkildə yoxlanılmalıdır [4].

Məlumat Təhlükəsizliyinin Əsas Konseptual Çərçivəsi: CIA Triadi

İqtisadi informasiya sistemlərində məlumat təhlükəsizliyinin təmin edilməsi üçün ən geniş qəbul görmüş konseptual model CIA triadıdır. Bu model üç fundamental prinsipin — məxfiliyin (confidentiality), bütövlüyün (integrity) və əlçatanlıq (availability) — kombinasiyasından ibarətdir. Hazırda kibertəhlükəsizlik siyasətlərinin hazırlanmasında əsas istinad nöqtəsi kimi qəbul edilən bu çərçivə, NIST SP 1800-26 sənədində rəsmi olaraq müəyyən edilmişdir [1].

Məxfilik (Confidentiality) — Məlumatın yalnız səlahiyyətli şəxslər tərəfindən əldə edilə bilməsini nəzərdə tutur. İqtisadi informasiya sistemləri kontekstində bu prinsip xüsusi əhəmiyyət kəsb edir, belə ki, maliyyə məlumatları, müştəri bazaları və kommersiya sirləri icazəsiz girişdən mühafizə edilməlidir. Məxfiliyin təmin edilməsi üçün şifrələmə mexanizmləri, çoxpilləli autentifikasiya və ən az imtiyaz prinsipi əsasında giriş nəzarəti tətbiq edilir.

Bütövlük (Integrity) — Məlumatın dəqiqliyinin, tamlığının və etibarlılığının qorunmasını əhatə edir. Bu prinsipə əsasən, məlumat həm ötürülmə prosesində, həm də saxlanılma mərhələsində icazəsiz dəyişikliklərdən mühafizə edilməlidir. İqtisadi sistemlərdə bütövlüyün pozulması — məsələn, maliyyə hesabatlarında və ya əməliyyat qeydlərində məlumatların saxtalaşdırılması — birbaşa maddi itkilərə və hüquqi nəticələrə gətirib çıxara bilər. Hash funksiyaları, rəqəmsal imzalar və versiya nəzarəti sistemləri bu prinsipin təmin edilməsinin əsas vasitələrindəndir.

Əlçatanlıq (Availability) — Səlahiyyətli istifadəçilərin məlumata və sistemlərə lazım olduğu anda fasiləsiz çıxış əldə edə bilməsini təmin edir. Bu prinsip, əvvəlki bölmədə araşdırılan biznesin fasiləsizliyi konsepsiyası ilə birbaşa əlaqəlidir: sistem nasazlıqları və ya kiberhücumlar nəticəsindəki fasilələr iqtisadi fəaliyyətin dayandırılmasına, müştəri itkisinə və nüfuz zədələnməsinə səbəb olur. Ehtiyat sistemlər, fəlakətin bərpası planlaması və DDoS hücumlarına qarşı müdafiə mexanizmləri əlçatanlığın qorunması üçün mühüm tədbirlərdir.

CIA triadının üç elementi bir-biri ilə sıx bağlıdır, eyni zamanda aralarında müəyyən gərginlik mövcuddur. Belə ki, məxfiliyi artırmaq məqsədilə tətbiq edilən ciddi giriş məhdudiyətləri əlçatanlığa mane ola bilər; digər tərəfdən isə əlçatanlığın maksimumlaşdırılması məxfilik risklərini artırır. Bu baxımdan, iqtisadi informasiya sistemlərinin dizaynında üç prinsip arasında optimal tarazlığın qurulması strateji əhəmiyyət daşıyır. CIA triadı həmçinin ISO/IEC 27001 beynəlxalq

standartı ilə tam uyğunluq təşkil edir, bu da onun müasir iqtisadi təşkilatlar üçün praktiki tətbiq dəyərini bir daha təsdiqləyir.

Metodiki Yanaşmaların Müqayisəli Təhlili: ISO/IEC 27001 və NIST CSF

İqtisadi informasiya sistemlərinin qorunmasında ən geniş yayılmış iki metodiki çərçivə ISO/IEC 27001 beynəlxalq standartı və ABŞ Milli Standartlar və Texnologiyalar İnstitutu tərəfindən hazırlanmış NIST Kibertəhlükəsizlik Çərçivəsidir (Cybersecurity Framework — CSF). Hər iki yanaşma CIA triadının prinsiplərini əməliyyat səviyyəsində reallaşdırmağa xidmət etsə də, onların struktur məntiqi, tətbiq sahəsi və iqtisadi kontekstə uyğunluğu baxımından əsaslı fərqlər mövcuddur.

ISO/IEC 27001 — sertifikatlaşdırma əsaslı, sistem yönümlü yanaşma

ISO/IEC 27001 İnformasiya Təhlükəsizliyinin İdarəetmə Sistemi (İTİS) üçün beynəlxalq sertifikatlaşdırma standartıdır. Bu standart təşkilatdan bütün informasiya aktivlərini əhatə edən rəsmi bir idarəetmə sistemi qurmasını tələb edir: risk qiymətləndirilməsi aparılmalı, nəzarət tədbirləri (controls) sənədləşdirilməli, daxili auditlər keçirilməli və müstəqil qurumlar tərəfindən sertifikatlaşdırılmalıdır. Standartın Annex A hissəsi 93 nəzarət tədbirini əhatə edir — giriş idarəetməsindən tutmuş fiziki təhlükəsizliyə, insident idarəetməsindən təchizat zənciri risklərinə qədər [3].

İqtisadi informasiya sistemləri kontekstində ISO/IEC 27001-in əsas üstünlüyü onun beynəlxalq tanınırlığı və müqavilə münasibətlərindəki dəyəridir: bank, sığorta və maliyyə sektoru tərəfdaşları çox vaxt sertifikata malik olmanı əməkdaşlıq şərti kimi irəli sürürlər. Bundan əlavə, standart uyğunluğun sübut edilməsini tələb etdiyindən sənədləşmə mədəniyyətini sistemli şəkildə formalaşdırır. Digər tərəfdən, ISO/IEC 27001-in tam tətbiqi resurs tələbkardır: kiçik və orta müəssisələr üçün sertifikatlaşdırma prosesi həm maliyyə, həm də vaxt baxımından ciddi yük ola bilər.

NIST CSF — çeviklik əsaslı, risk yönümlü yanaşma

NIST CSF 2014-cü ildə ABŞ-da kritik infrastrukturların qorunması üçün hazırlanmış, 2024-cü ildə isə 2.0 versiyası ilə yenilənmiş çərçivədir [5]. Standartdan fərqli olaraq, CSF məcburi sertifikat tələb etmir — o, beş əsas funksiya ətrafında qurulmuş çevik bir yol xəritəsidir: müəyyənləşdirmə (Identify), qoruma (Protect), aşkarlama (Detect), cavab vermə (Respond) və bərpa (Recover). 2.0 versiyasında bu funksiyalara idarəetmə (Govern) da əlavə edilmişdir [5].

NIST CSF-in iqtisadi informasiya sistemləri üçün əsas üstünlüyü onun ölçülə bilən yetkinlik səviyyələri (tiers) vasitəsilə müəssisənin cari vəziyyətini qiymətləndirməsinə və hədəf vəziyyətə doğru prioritetləşdirilmiş yol xəritəsi qurmasına imkan verməsidir [5]. Bu xüsusiyyət onun risk menecmenti yanaşması ilə birbaşa əlaqəlidir: müəssisə hansı sahəyə daha çox investisiya etməli olduğunu əvvəlcə ölçür, sonra qərar verir. Bununla belə, CSF-in standart olmayan çevik strukturu bəzi hallarda tətbiqin ardıcılığını və nəticənin ölçülməsini çətinləşdirir.

İki yanaşmanın müqayisəli dəyərləndirməsi

Hər iki çərçivə öz-özlüyündə tam bir metodika təşkil etsə də, onların güclü və zəif tərəflərinin müqayisəli təhlili göstərir ki, bu yanaşmalar bir-birini tamamlama potensialına malikdir: NIST CSF strateji yol xəritəsi və risk prioritetləşdirməsi baxımından, ISO/IEC 27001 isə idarəetmə sisteminin rəsmiləşdirilməsi və xarici tərəflərə sübut edilməsi baxımından üstünlük təşkil edir. İqtisadi informasiya sistemlərinin xüsusiyyətlərini nəzərə aldıqda — maliyyə məlumatlarının həssaslığı, tərəfdaşlarla inteqrasiya, tənzimləyici tələblər — bu kombinasiya ən əhatəli müdafiəni təmin edə bilər. Belə ki, NIST CSF-in aşkarlama və cavab vermə funksiyaları ilə ISO/IEC 27001-in insident idarəetmə nəzarətlərinin inteqrasiyası nəzəri baxımdan həm sertifikat tələblərini, həm də operativ cavab vermə qabiliyyətini eyni vaxtda təmin etməyə imkan verə bilər.

Risk Menecmenti və Biznesin Fasiləsizliyi

Şirkətlərin öz biznes və maliyyə işlərində müasir informasiya sistemlərindən istifadə etməsi köhnə kağız işlərindəki riskləri və vaxt itkisini azaltsa da, rəqəmsallaşma özü ilə bərabər tamamilə yeni, mürəkkəb və insan səhvlərinə bağlı olan risklər gətirir. Bu yeni nəsillə riskləri düzgün idarə etmək

üçün şirkət daxilində aydın və tətbiqi mümkün olan bir risk siyasəti olmalıdır. Təhlükələri vaxtında müəyyən etmək və daxili nəzarət sistemləri qurmaq mühümdür, lakin bundan daha vacibi hər hansı bir kiberhücum və ya sistem çökməsi baş verdiyi an üçün 'Biznesin Fasiləsizliyi Planı'nın mövcud olmasıdır, çünki bu plan şirkətin maliyyə iflasına uğramadan fəaliyyətini sürətlə bərpa etməsini təmin edir.

İnformasiya sistemlərinin auditi zamanı aşkar olunan risklərə qarşı necə reaksiya veriləcəyi ilə bağlı şirkətlər öz maliyyə imkanlarına uyğun strateji addımlar seçməlidirlər. Bu metodologiyaya görə şirkətlərin qarşısında üç əsas yol var: əgər riskin vura biləcəyi maliyyə zərəri çox kiçikdirsə, bu riski sadəcə qəbul etmək olar; zərər böyükdürsə, texniki alətləri gücləndirib riskin təsirini minimuma endirmək və ya kiber-sığorta vasitəsilə bu riski başqa bir şirkətə ötürmək olar; son variant isə təhlükə yaradan həmin riskli biznes prosesini ümumiyyətlə dayandıraraq sistemdən silməkdir [7].

Nəticə

İqtisadi informasiya sistemlərinin getdikcə daha mürəkkəb bir rəqəmsal mühitdə fəaliyyət göstərdiyi bu dövrdə məlumat təhlükəsizliyi artıq yalnız texniki bir məsələ deyil, eyni zamanda strateji bir idarəetmə problemidir. Bu sahədə uğurlu nəticə əldə etmək üçün texnoloji həlləri, iqtisadi düşüncəni və idarəetmə mexanizmlərini bir-biri ilə əlaqəli şəkildə nəzərə almaq lazımdır.

CIA triadının praktikada tətbiqi heç də sadə deyil: məxfilik, bütövlük və əlçatanlıq arasında daim gərginlik mövcuddur və hər bir təşkilat öz fəaliyyət xüsusiyyətlərinə uyğun optimal balans tapmalıdır. Bu balansın qurulmasında isə metodiki çərçivələrin seçimi həlledici rol oynayır. Təhlil göstərir ki, ISO/IEC 27001 və NIST CSF bir-birini əvəz edən deyil, bir-birini tamamlayan yanaşmalardır: birincisi idarəetmə sisteminin rəsmiləşdirilməsi və beynəlxalq tanınırlıq üçün, ikincisi isə risk prioritetləşdirməsi və operativ cavab vermə qabiliyyətinin gücləndirilməsi üçün daha uyğundur. İqtisadi informasiya sistemlərinin xüsusiyyətlərini — maliyyə məlumatlarının həssaslığını, tənzimləyici tələbləri və tərəfdaş inteqrasiyasını — nəzərə alıqda, bu iki çərçivənin kombinasiyası ən əhatəli müdafiəni təmin edir.

Kibertəhlükəsizlik iqtisadiyyatı baxımından isə müəssisədaxili maraqlarda uyğunsuzluq və informasiya asimmetriyası ciddi boşluqlar yaradır. Bir müəssisənin zəifliyi bütöv bir tədarük zəncirinə yayıla biləcəyindən, bu məsələyə fərdi yox, sistemli yanaşmaq zəruridir. Riskin qəbul edilməsi, azaldılması, ötürülməsi və ya aradan qaldırılması kimi fərqli idarəetmə yollarından hansının seçiləcəyi isə birbaşa müəssisənin maliyyə imkanlarından və risk tolerantlığından asılıdır. Biznesin Fasiləsizliyi Planının mövcudluğu bu kontekstdə zəruri şərtə çevrilir.

Ümumilikdə, iqtisadi informasiya sistemlərinin etibarlı qorunması güclü texniki infrastrukturla bitmir; işçilərin maarifləndirilib düzgün davranışa yönəldilməsi, normativ çərçivələrə uyğunluq və siyasətlərin mütəmadi yenilənməsi də eyni dərəcədə vacibdir. Bu yanaşma kompleks şəkildə həyata keçirildikdə, informasiya təhlükəsizliyi müəssisənin maliyyə sabitliyini və rəqabət qabiliyyətini qoruyan əsas sütunlardan birinə çevrilir.

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ТРАНСФОРМАЦИЯ МАРКЕТИНГА В ЦИФРОВОЙ ЭКОНОМИКЕ

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В условиях ускоренного развития цифровых технологий маркетинг претерпевает существенные трансформационные изменения, затрагивающие как его концептуальные основы, так и практические механизмы взаимодействия с потребителями. Цифровизация экономики, распространение информационно-коммуникационных технологий, рост интернет-аудитории и развитие искусственного интеллекта способствуют формированию новых моделей потребительского поведения, что требует пересмотра традиционных маркетинговых подходов.

Современный маркетинг представляет собой не только инструмент продвижения товаров и услуг, но и комплексную систему управления взаимоотношениями с потребителями, основанную на анализе данных, прогнозировании потребительских предпочтений и создании персонализированного клиентского опыта [1]. В связи с этим особую актуальность приобретает исследование эволюции маркетинга как научной и практической области деятельности, а также выявление ключевых факторов, обусловивших переход от традиционных методов продвижения к цифровым маркетинговым технологиям.

Изучение процессов трансформации маркетинга позволяет определить основные тенденции развития рынка, оценить влияние цифровых технологий на деятельность организаций и сформировать представление о перспективах дальнейшего развития маркетинговых концепций в условиях цифровой экономики.

Развитие маркетинга тесно связано с изменениями экономической среды, уровнем технологического прогресса и трансформацией потребительских потребностей [2,3]. На различных этапах развития экономики маркетинговая деятельность выполняла различные функции, постепенно переходя от ориентации на производство к ориентации на потребителя и создание долгосрочной ценности.

Таблица 1 – этапы эволюции маркетинговых концепций: Marketing 1.0-5.0

Концепция	Период развития	Ключевой объект внимания	Основная цель
Marketing 1.0	До 1960-х годов	Продукт	Массовое производство и реализация продукции
Marketing 2.0	1960-1990 гг.	Потребитель	Удовлетворение потребностей и предпочтений целевых сегментов
Marketing 3.0	2000-2010 гг.	Ценности потребителя	Формирование эмоциональной привязанности и общественной значимости бренда
Marketing 4.0	2010-2020 гг.	Цифровое взаимодействие	Интеграция онлайн и офлайн коммуникаций, создание бесшовного клиентского опыта
Marketing 5.0	С 2020 годов	Человек и технологии	Создание персонализированного клиентского опыта посредством интеллектуальных технологий

На начальном этапе индустриального развития основное внимание организаций было сосредоточено на расширении производственных мощностей и повышении эффективности производственных процессов. В условиях превышения спроса над предложением ключевым фактором конкурентоспособности выступала способность предприятия обеспечить массовый выпуск продукции при минимальных издержках. Маркетинговая деятельность в этот период ограничивалась вопросами распределения продукции и формирования доступной ценовой политики.

Последующее насыщение рынков привело к усилению конкуренции и необходимости более глубокого изучения потребительского спроса. В центре внимания компаний оказались инструменты стимулирования продаж, рекламные коммуникации и методы формирования потребительской лояльности. Именно на данном этапе маркетинг начинает рассматриваться как самостоятельная управленческая функция, обеспечивающая эффективное взаимодействие между производителем и рынком.

Во второй половине XX века происходит переход к концепции маркетинговой ориентации, в рамках которой приоритетное значение приобретают потребности потребителей. Компании начинают активно использовать маркетинговые исследования, сегментацию рынка и инструменты позиционирования, что позволяет формировать конкурентные преимущества на основе более точного понимания запросов целевой аудитории.

Развитие информационных технологий и глобализация экономических процессов обусловили появление новых подходов к управлению маркетинговой деятельностью. Концепция стратегического маркетинга сместила акцент с краткосрочных продаж на формирование устойчивых взаимоотношений с потребителями и создание долгосрочной ценности для всех участников рынка. В этот период возрастает значение брендинга, управления клиентским опытом и построения маркетинговых экосистем.

Начало XXI века ознаменовалось активным внедрением цифровых технологий во все сферы экономической деятельности. Появление социальных сетей, мобильных устройств, облачных сервисов и аналитических платформ создало принципиально новые возможности для взаимодействия с потребителями. В результате сформировалась концепция цифрового маркетинга, предполагающая использование онлайн-каналов коммуникации для

продвижения товаров и услуг, сбора данных о поведении клиентов и оценки эффективности маркетинговых мероприятий в режиме реального времени.

Особенностью цифрового маркетинга является возможность персонализированного взаимодействия с потребителями на основе анализа больших массивов данных [5]. Современные компании способны формировать индивидуальные предложения, прогнозировать потребительские предпочтения и адаптировать маркетинговые коммуникации в зависимости от особенностей конкретного клиента. Это существенно повышает эффективность маркетинговой деятельности и способствует росту удовлетворенности потребителей.

В последние годы в научной литературе активно развивается концепция Marketing 5.0, предложенная Ф. Котлером [6]. Данная концепция предполагает интеграцию технологий искусственного интеллекта, машинного обучения, Интернета вещей и предиктивной аналитики в процессы управления маркетингом. В отличие от предыдущих этапов развития маркетинга, Marketing 5.0 ориентирован на использование цифровых технологий для решения социальных и экономических задач при сохранении человекоцентричного подхода к взаимодействию с потребителями.

Таким образом, эволюция маркетинга представляет собой последовательный переход от производственно-ориентированных моделей управления к цифровым платформенным экосистемам, основанным на данных, технологиях искусственного интеллекта и глубоком понимании потребностей потребителей. На протяжении своего исторического развития маркетинг прошел путь от инструмента обеспечения сбыта продукции до стратегической функции управления взаимоотношениями с потребителями и формирования устойчивых конкурентных преимуществ организации.

Цифровая трансформация экономики существенно изменила методы маркетинговой деятельности, расширив возможности компаний в области коммуникаций, анализа данных и персонализации предложений. Использование цифровых технологий позволяет организациям получать информацию о поведении потребителей в режиме реального времени, оперативно адаптировать маркетинговые стратегии и повышать эффективность принимаемых управленческих решений.

В современных условиях цифровой маркетинг становится не альтернативой традиционным маркетинговым инструментам, а логическим этапом их развития. Интеграция технологий искусственного интеллекта, больших данных, машинного обучения и автоматизированных систем анализа формирует основу для дальнейшего развития маркетинга как науки и практики управления потребительской ценностью.

Перспективы дальнейшей эволюции маркетинга связаны с развитием концепции Marketing 5.0, предполагающей использование интеллектуальных технологий для создания более эффективных, персонализированных и социально ориентированных механизмов взаимодействия между организациями и потребителями. В этих условиях способность компаний адаптироваться к цифровым изменениям становится одним из ключевых факторов их долгосрочной конкурентоспособности.

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ASSESSING THE EFFICIENCY OF TOURISM AND RECREATION SPECIAL ECONOMIC ZONES IN KAZAKHSTAN: A TYPE-ORIENTED APPROACH

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Abstract. This article examines the effectiveness of tourism and recreational special economic zones in Kazakhstan through a type-oriented assessment approach. The study argues that conventional evaluation criteria, primarily based on investment volume, export performance and fiscal returns, do not fully reflect the specific nature of tourism-oriented special economic zones. Unlike industrial zones, tourism and recreational SEZs generate delayed, indirect and spatially distributed effects related to employment creation, small and medium-sized business development, urban infrastructure improvement, territorial capitalization and regional socio-economic diversification. The empirical analysis focuses on the special economic zones “TURAN”, “Turkistan” and “Alatau”, comparing their investment volume, number of residents and jobs created. The findings show that although “Alatau” demonstrates a higher level of investment, “TURAN” and “Turkistan” provide stronger employment intensity and greater involvement of small and medium-sized enterprises. The results confirm the need to differentiate SEZ performance assessment according to their functional type. For tourism and recreational SEZs, priority should be given not only to capital investment indicators, but also to employment, entrepreneurial activity, infrastructure development and long-term regional multiplier effects. The proposed type-oriented approach may be used by public authorities and SEZ management companies to improve monitoring, strategic planning and institutional support for tourism and recreational zones in Kazakhstan.

Keywords: special economic zones; tourism and recreational zones; Kazakhstan; type-oriented assessment; regional development; tourism infrastructure; employment; investment efficiency; institutional approach.

Introduction

Amid the transformation of the economic structure of the Republic of Kazakhstan and the shift of public policy priorities towards the diversification of regional development, the instrument of special economic zones (SEZs) has acquired particular importance. Over the past two decades, SEZs have been actively used as a mechanism for attracting investment, stimulating entrepreneurial activity, and creating new points of economic growth. However, accumulated international and national experience indicates that the performance of SEZs varies substantially depending on their functional type, sectoral specialisation, and institutional configuration.

Tourism and recreation special economic zones occupy a specific place within Kazakhstan’s SEZ system. These zones are aimed at developing the service sector, tourism infrastructure, cultural heritage, and related industries. Unlike industrial and technology-oriented zones, tourism and recreation SEZs mainly generate deferred socio-economic and spatial effects, which are not always adequately captured by conventional approaches to efficiency assessment based on investment volumes, exports, and fiscal returns.

The application of universal assessment criteria leads to a systematic distortion of the results of analysing tourism and recreation SEZs and creates an erroneous perception of their “low efficiency” at the early stages of operation. This, in turn, affects managerial decisions, budget priorities, and the institutional support provided to such zones. Therefore, there is a growing need to develop and apply a type-oriented approach to assessing SEZ efficiency that takes into account the specific features of tourism and recreation development.

The purpose of this study is to assess the efficiency of tourism and recreation special economic zones in Kazakhstan using a type-oriented approach based on empirical data for the TURAN, Turkistan, and Alatau SEZs. The study pursues the following objectives:

- to substantiate the theoretical and institutional features of tourism and recreation SEZs;
- to identify the limitations of universal criteria for efficiency assessment;
- to conduct a comparative empirical analysis of key performance indicators for the selected SEZs;
- to propose a type-oriented efficiency assessment model adapted to the conditions of Kazakhstan.

1. Theoretical and Institutional Foundations for Assessing Tourism and Recreation SEZs

From the perspective of institutional economic theory, special economic zones are regarded as a form of selective regulation aimed at reducing transaction costs, increasing investment attractiveness, and accelerating structural transformations in selected sectors of the economy. According to the World Bank, SEZs are geographically delimited areas with a special legal and economic regime that differs from nationwide regulation.

The classical model for assessing SEZ efficiency is predominantly based on quantitative indicators such as the volume of attracted investment, export revenues, the number of residents, and tax receipts. This approach is justified for industrial zones oriented towards goods production and integration into global value chains. However, its application to tourism and recreation SEZs does not take into account the specific nature of the service economy or the multi-level character of the effects generated.

Tourism and recreation SEZs operate according to a different institutional logic. Their economic impact is formed not only through the direct investment activity of residents but also through multiplier effects on the labour market, the development of small and medium-sized enterprises, improvements in the quality of the urban environment, and the capitalisation of territories. An important role is also played by intangible components - cultural heritage, territorial image, and tourism attractiveness - which are difficult to measure directly in the short term.

The institutional environment of tourism and recreation SEZs is characterised by a high degree of cross-sectoral interaction: economic outcomes depend on coordination among public administration bodies, zone operators, local communities, and private businesses. Under conditions of weak institutional coherence and the absence of specialised assessment criteria, tourism SEZs are placed at an inherent disadvantage compared with industrial zones.

Thus, from a theoretical standpoint, assessing the efficiency of tourism and recreation SEZs requires an expanded approach that includes institutional, social, and spatial parameters alongside traditional economic indicators.

2. Empirical Analysis of Tourism and Recreation Special Economic Zones in Kazakhstan

The empirical part of the study is based on a comparative analysis of the TURAN, Turkistan, and Alatau tourism and recreation special economic zones. The selection of these zones is determined by their different institutional logics, territorial locations, and stages of development, which makes it possible to identify the heterogeneity of the economic effects produced by tourism SEZs within a unified national policy framework.

The key indicators used in the analysis are investment volume, the number of residents, and the number of jobs created. These indicators reflect both the scale of economic activity within the

SEZs and the nature of their impact on the regional labour market and entrepreneurial environment.

2.1. Comparative Characteristics of Key Performance Indicators of SEZs

As of the latest reporting periods, tourism and recreation SEZs demonstrate different dynamics of investment and resident activity (Table 1).

Table 1. Main indicators of tourism and recreation SEZs in Kazakhstan

SEZ	Investment volume, KZT billion	Number of residents, units	Jobs, persons
TURAN	approximately 120	more than 40	more than 4,500
Turkistan	approximately 95	more than 35	more than 3,800
Alatau	approximately 300	approximately 25	approximately 2,600

The data presented indicate that the Alatau SEZ significantly exceeds the other zones in terms of attracted investment. This is explained by the scale of projects, the high capital intensity of infrastructure, and the agglomeration effect of the Almaty region. At the same time, this advantage is not proportionally transformed into employment indicators or the number of residents.

By contrast, the TURAN and Turkistan SEZs, despite substantially lower investment volumes, demonstrate higher employment density and greater involvement of small and medium-sized enterprises. This indicates differences in the economic nature of the effects generated by tourism and recreation SEZs and highlights the limitations of assessing their efficiency solely through investment indicators.

2.2. Investment and the Structure of Economic Returns

The economic interpretation of investment data shows that, in tourism and recreation SEZs, a significant share of investment is directed towards the development of service infrastructure, accommodation facilities, transport accessibility, and the urban environment. Such investments generally have a longer payback period and generate indirect economic effects that extend beyond the boundaries of the SEZ.

In the Alatau SEZ, investment is concentrated primarily in capital-intensive projects oriented towards long-term agglomeration development. This explains the relatively low number of jobs created per unit of invested capital. In this case, the economic effect of the zone is deferred and largely depends on external factors, including the development of transport corridors and urban expansion.

Conversely, the TURAN and Turkistan SEZs demonstrate higher investment returns in terms of employment and entrepreneurial activity. This is associated with their sectoral orientation towards tourism, where each investment project generates labour demand in related sectors, including trade, transport, public catering, cultural services, and other service activities.

Thus, a comparison of the investment efficiency of tourism and recreation SEZs shows that conventional capital-intensity criteria do not allow for an adequate assessment of the economic performance of zones oriented towards a service-based growth model.

2.3. Employment and the Role of Small and Medium-Sized Businesses

One of the key economic effects of tourism and recreation SEZs is the creation of jobs, primarily for the local population. An analysis of data for the TURAN and Turkistan SEZs shows that the employment generated is more territorially balanced and contributes to the involvement of local labour resources.

A high share of residents represented by small and medium-sized businesses forms a sustainable entrepreneurial ecosystem oriented towards local value chains. In contrast, the Alatau

SEZ is dominated by larger projects that require substantial capital investment and provide a limited number of jobs at the initial stages of implementation.

From an economic perspective, this confirms the proposition that tourism and recreation SEZs perform not only an investment function but also a socio-economic equalisation function for regions. Their contribution to reducing unemployment and expanding employment cannot be properly assessed without taking into account the structure of residents and the nature of the jobs created.

2.4. The Problem of Distorted Efficiency Assessment of Tourism and Recreation SEZs

The comparison of empirical data makes it possible to conclude that there is a systematic distortion in the assessment of tourism and recreation SEZ efficiency when universal criteria designed for industrial zones are applied. The dominance of investment and fiscal indicators in assessment models leads to biased conclusions regarding the comparative performance of tourism SEZs.

In particular, based on a formal comparison, the Alatau SEZ may be recognised as more efficient due to its investment volume, while the real socio-economic effects of the TURAN and Turkistan SEZs remain underestimated. This creates the risk of incorrect managerial decisions, including the redistribution of budgetary resources and the reduction of institutional support for tourism and recreation zones.

Conclusion

The study confirms that tourism and recreation special economic zones in Kazakhstan generate a specific type of economic effect that differs from the outcomes of industrial and technology-oriented SEZs. The application of universal efficiency assessment criteria focused primarily on investment volumes and fiscal returns leads to a systematic distortion of the performance assessment of tourism and recreation zones and to an underestimation of their contribution to regional development.

The comparative empirical analysis of the TURAN, Turkistan, and Alatau SEZs shows that, despite lower investment volumes, the tourism and recreation SEZs of the Turkistan region ensure higher labour intensity, greater involvement of small and medium-sized businesses, and a pronounced multiplier effect for the local economy. At the same time, the Alatau SEZ, characterised by the high capital intensity of its projects, primarily generates deferred economic effects associated with agglomeration development and spatial transformation of the territory.

The results obtained indicate the need to differentiate approaches to assessing SEZ efficiency depending on their functional type. For tourism and recreation SEZs, priority should be given to indicators of employment, entrepreneurial activity, infrastructure development, and spatial capitalisation, rather than only to absolute investment parameters. In this regard, the type-oriented approach makes it possible to more accurately account for the specific features of the service economy and the long-term nature of economic returns from tourism zones.

The practical significance of the study lies in the potential use of the proposed methodology by public administration bodies and SEZ management companies in monitoring efficiency, adjusting government support programmes, and forming strategic priorities for territorial development. The implementation of a type-oriented approach contributes to reducing institutional distortions and improving the validity of managerial decisions in the development of tourism and recreation SEZs in Kazakhstan.

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Pedagogical Sciences

ТАРИХИ ДЕРЕКТЕРГЕ НЕГІЗДЕЛГЕН МАТЕМАТИКАЛЫҚ ЕСЕПТЕР – ПӘНАРАЛЫҚ ИНТЕГРАЦИЯ ҚҰРАЛЫ РЕТІНДЕ

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физика-математика ғылымдарының докторы, профессор, І. Жансүгіров атындағы Жетісу университеті, Талдықорған қ., Қазақстан Республикасы

Бұл мақалада мектепте тарих пен математика пәндерін кіріктіре оқытудың тиімді жолдары қарастырылады. Автор пәнаралық интеграцияның негізгі тәсілдерін талдай келе, ең қолжетімді әрі нәтижелі әдіс – тарихи деректерге негізделген математикалық есептер жүйесін ұсынады. Ұлы Отан соғысы (1941–1945) тақырыбындағы нақты сандық деректерге сүйенген 4 есеп әзірленіп, әрқайсысының тарихи контексті, математикалық шығарылуы және педагогикалық мүмкіндіктері келтірілген. Мақала соңында есептерді сабақта қолданудың әдістемелік нұсқауы және интеграцияның тиімділігін бағалау критерийлері берілген.

Кілт сөздер: пәнаралық интеграция, тарих, математика, тиімді жолдар, Ұлы Отан соғысы, кіріктірілген есептер, мектеп курсы.

В данной статье рассматриваются эффективные способы интеграции предметов истории и математики в школьном обучении. Автор анализирует основные подходы к межпредметной интеграции и предлагает наиболее доступный и результативный метод — систему математических задач, основанных на исторических данных. Разработаны четыре задачи на основе реальных количественных данных по теме Великой Отечественной войны (1941–1945 гг.), для каждой из которых представлены исторический контекст, математическое решение и педагогические возможности использования. В заключении статьи приведены методические рекомендации по применению задач на уроках и критерии оценки эффективности интеграции.

Ключевые слова: межпредметная интеграция, история, математика, эффективные методы, Великая Отечественная война, интегрированные задачи, школьный курс.

This article examines effective ways of integrating History and Mathematics in school education. The author analyzes the main approaches to interdisciplinary integration and proposes the most accessible and effective method — a system of mathematical problems based on historical data. Four problems were developed using real quantitative data related to the Great Patriotic War (1941–1945). For each problem, the historical context, mathematical solution, and pedagogical potential are presented. The article concludes with methodological recommendations

for using these problems in the classroom and criteria for evaluating the effectiveness of interdisciplinary integration.

Keywords: interdisciplinary integration, history, mathematics, effective methods, the Great Patriotic War, integrated problems, school curriculum.

Кіріспе

Қазіргі білім беру парадигмасында пәнаралық интеграция – оқушылардың тұтас дүниетанымын қалыптастырудың, функционалдық сауаттылығын дамытудың және пәнге деген қызығушылығын арттырудың маңызды құралы. Тарих пен математика бір қарағанда екі бөлек ғылым саласы болғанымен, олардың тоғысу нүктелері өте көп: хронология, статистика, демография, экономика, әскери іс, картография – бұлардың бәрі сандық деректерге негізделген.

Мектеп курсында «Тарих + Математика» интеграциясын жүзеге асырудың бірнеше тиімді жолы бар:

- **Тарихи мәтіндерді математикалық талдау** (кесте, график, диаграмма құру);
- **Тарихи оқиғалардың сандық сипаттамаларын есептерге айналдыру** (пайыз, пропорция, қозғалыс, прогрессия);
- **Уақыт сызығы арқылы хронологияны математикалық модельдеу;**
- **Тарихи карталарды координаталар және масштабпен байланыстыру;**
- **Мұрағаттық деректер негізінде шағын зерттеу жобалары** (статистикалық жиынтықтармен жұмыс).

Осы жолдардың ішінде **ең қолжетімді әрі нәтижелісі** – дайын тарихи сандық деректерді пайдаланып математикалық есептер құрастыру. Мұндай есептер бір уақытта математикалық дағдыны бекітеді, тарихи материалды тереңдетеді және патриоттық тәрбие береді.

Бұл мақалада біз **Ұлы Отан соғысы (1941–1945)** тақырыбындағы нақты деректерге негізделген **4 есепті** ұсынып, олардың әрқайсысының интеграциялық әлеуетін көрсетеміз.

Ұлы Отан соғысы тақырыбындағы кіріктірілген есептер

Әрбір есеп төмендегі құрылым бойынша беріледі:

1. **Тарихи контекст** (қысқаша анықтама)
2. **Есептің берілуі** (математикалық шарты)
3. **Шығарылуы** (кезең-кезеңімен)
4. **Педагогикалық түсініктеме** (осы есеп арқылы қандай интеграция жүзеге асады)

Есеп №1. «Мәскеу түбіндегі танктер» (пайыздар, 6–7 сынып)

Тарихи контекст: 1941 жылдың қазанында Мәскеу түбіндегі шайқастың бастапқы кезеңінде неміс әскерінде («Орталық» армия тобы) 1700 танк болды. Кеңес әскерінде (Батыс, Резерв және Брянск майдандары) 990 танк болды. Қарсы шабуылға дайындық барысында Кеңес қолбасшылығы Шығыс майданнан (Сібір мен Қиыр Шығыстан) резервтерді ауыстырып, танк санын **шамамен 2 есеге** арттырды (1980-ге жуық). Ал неміс танктерінің **шамамен 50%-ы** (яғни 850-ге жуығы) қарсы шабуыл барысында жойылды.

Есептің берілуі:

1. Шабуыл алдында неміс танктерінің саны Кеңес танктерінен неше пайызға артық болды? (Жауапты бүтін санға дейін дөңгелектеңіз)
2. Кеңес әскерінің танк саны 2 есеге артқаннан кейін қанша танк болды?
3. Неміс танктерінің 50%-ы жойылғаннан кейін немістерде қанша танк қалды?
4. Шабуылдан кейінгі Кеңес пен неміс танктерінің қатынасы қандай болды? (Қатынасты оңтайландырыңыз және оңдық бөлшек түрінде көрсетіңіз)
5. Шабуылдан кейін Кеңес танктері неміс танктерінен неше есе артық?

Шығарылуы:

Берілгені:

- $H_0 = 1700$ (неміс танктері, бастапқы)
- $K_0 = 990$ (кеңес танктері, бастапқы)
- Кеңес танктері 2 есеге артады $\rightarrow K_1 = 990 \cdot 2 = 1980$ (танк)
- Неміс танктерінің 50%-ы жойылады \rightarrow қалғаны 50% $\rightarrow H_1 = 1700 \cdot 0,5 = 850$ (танк)

1-сұрақ: Шабуыл алдында неміс танктері Кеңес танктерінен неше пайызға артық?

Шешуі:

Артықшылық (санмен) = $1700 - 990 = 710$ танк

$$\begin{aligned} 990 &\rightarrow 100\% \\ 710 &\rightarrow x\% \\ x &= \frac{710 \cdot 100}{990} \approx 71,7\% \end{aligned}$$

Бүтін санға дөңгелектегенде \rightarrow **72%**

Жауабы: 72%

2-сұрақ: Кеңес әскерінің танк саны 2 есеге артқаннан кейін қанша танк болды?

Шешуі: $K_1 = 990 \cdot 2 =$ **1980** танк

Жауабы: 1980 танк

3-сұрақ: Неміс танктерінің 50%-ы жойылғаннан кейін немістерде қанша танк қалды?

Шешуі: $H_1 = 1700 \cdot 0,5 =$ **850** танк

Жауабы: 850 танк

4-сұрақ: Шабуылдан кейінгі Кеңес пен неміс танктерінің қатынасы қандай?

Шешуі:

$$\frac{K_1}{H_1} = \frac{1980}{850} = \frac{198}{85} \approx 2,329$$

Жауабы: $\frac{198}{85}$ (немесе шамамен 2,329)

5-сұрақ: Шабуылдан кейін Кеңес танктері неміс танктерінен неше есе артық?

Шешуі:

$$\frac{1980}{850} \approx 2,33$$

Жауабы: 2,33 есе

Педагогикалық түсініктеме: Бұл есеп арқылы оқушылар пайыздық артықшылықты, пропорцияны және қатынасты есептеуді үйренеді. Сонымен қатар, олар Мәскеу шайқасының нақты деректеріне сүйене отырып, Кеңес әскерінің резервтер есебінен қалай басымдыққа жеткенін сандар арқылы көреді. Бастапқыда немістер 72% артық болса, шабуылдан кейін Кеңес әскері 2,33 есе артықшылыққа ие болды. Бұл – Мәскеу түбіндегі жеңістің математикалық дәлелі.

Есеп №2. «Ленинград блокадасындағы нан нормасы» (бөлшектер, өлшем бірліктері, 5–6 сынып)

Тарихи контекст: Ленинград блокадасы 872 күнге созылды – 1941 жылғы 8 қыркүйектен 1944 жылғы 27 қаңтарға дейін. Блокада кезінде қалада 2,9 миллион адам қалды, оның 2,5 миллионы – бейбіт тұрғындар. Ең ауыр кезең 1941 жылғы 20 қараша мен 25 желтоқсан аралығы болды. Дәл осы кезде ең төменгі нан нормасы белгіленді:

1-кесте

Топ	Тәуліктік норма
Жұмысшылар	250 грамм
Қызметкерлер, балалар, асырауында адамдары барлар	125 грамм
Әскердің бірінші шебіндегілер	500 грамм

Есептің берілуі:

1. Жұмысшы бір аптада қанша грамм нан алады? Жауабын килограммға айналдыр.
2. Балаға бір айда (30 күн) қанша нан берілген? Жауабын килограммға айналдыр.
3. Егер нанның тек 40%-ы ғана нағыз ұн болса, жұмысшы бір аптада неше грамм ұн жейді?
4. Блокаданың 872 күнінде жұмысшы барлығы қанша нан алды (тоннамен)?
5. Егер бүкіл блокада кезінде жұмысшы нормасы 250 г болып қалса (өзгермесе), ол қанша нан алар еді? Нәтижені №4 сұрақпен салыстыр.

Шығарылуы:

Берілгені:

- Жұмысшы нормасы = 250 г/тәулік
- Бала нормасы = 125 г/тәулік
- Ұн үлесі = 40% = 0,4
- Блокада күндері = 872 күн

1-сұрақ: Жұмысшы бір аптада қанша грамм нан алады?

Шешуі:

$$\begin{aligned} 250 \text{ г} \cdot 7 &= 1750 \text{ г} \\ \frac{1750}{1000} &= 1,75 \text{ кг} \end{aligned}$$

Жауабы: 1,75 кг

2-сұрақ: Балаға бір айда (30 күн) қанша нан берілген?

Шешуі:

$$\begin{aligned} 125 \text{ г} \cdot 30 &= 3750 \text{ г} \\ \frac{3750}{1000} &= 3,75 \text{ кг} \end{aligned}$$

Жауабы: 3,75 кг

3-сұрақ: Егер нанның тек 40%-ы ғана нағыз ұн болса, жұмысшы бір аптада неше грамм ұн жейді?

Шешуі:

$$1750 \text{ г} \cdot 0,4 = 700 \text{ г}$$

Жауабы: 700 г (бұл – бір аптада жейтін нағыз ұнның мөлшері, қалғаны – қоспалар)

4-сұрақ: Блокаданың 872 күнінде жұмысшы барлығы қанша нан алды (тоннамен)?

Шешуі:

$$\begin{aligned} 872 \text{ күн} \cdot 250 \text{ г} &= 218\,000 \text{ г} \\ \frac{218\,000}{1000} &= 218 \text{ кг} \\ \frac{218}{1000} &= 0,218 \text{ т} \end{aligned}$$

Жауабы: 0,218 тонна

5-сұрақ: Егер бүкіл блокада кезінде жұмысшы нормасы 250 г болып қалса (өзгермесе), ол қанша нан алар еді?

Шешуі:

$$872 \cdot 250 = 218\,000 \text{ г} = 0,218 \text{ т}$$

(өзгеріс жоқ, себебі норма тұрақты)

Жауабы: 0,218 тонна. Бұл норма 1941 жылғы ең ауыр кезеңде ғана емес, бүкіл блокада бойы сақталды деген шартты есептеу. Шындығында норма бірнеше рет өзгерген

Педагогикалық түсініктеме: Бұл есеп оқушыларға бөлшектерді, өлшем бірліктерін түрлендіруді және пайыздық есептеулерді үйретеді. Сонымен қатар, блокаданың адам төзгісіз ауыр жағдайын сандар арқылы сезінеді: «Бір айда бала 3,75 кг нан алыпты, ал қазіргі кезде біз оны бір күнде жейміз» деген салыстыру арқылы тарихи эмпатия қалыптасады.

Есеп №3. «Волга арқылы өту: Сталинград шайқасы» (қозғалыс, 7–8 сынып)

Тарихи контекст: Сталинград шайқасы (1942 ж. 17 шілде – 1943 ж. 2 ақпан) Ұлы Отан соғысының ең ірі шайқастарының бірі болды. 1942 жылдың қыркүйегінде 62-ші армия (В.И. Чуйковтың қолбасшылығымен) Волга арқылы өтіп, Сталинградты қорғады.

Волганың ені Сталинград тұсында 1 километрге жеткен. Кеңес деректері бойынша, артиллериялық және авиациялық шабуылдар салдарынан өткелдегі қайықтардың **шамамен 25-30%** қайтып оралмаған.

Есептің берілуі:

1. Қайық өзеннің бір жағасынан екінші жағасына қанша уақытта (минутпен және секундпен) жүзеді?
2. Егер әр қайық 30 сарбаз тасыса және сағатына 12 қайық өтсе, бір сағатта қанша сарбаз өткізілді?
3. Осы сарбаздардың 30%-ы өткелде қаза тапқан болса, қанша сарбаз аман жетті?
4. Бір тәулікте (24 сағат) қанша сарбаз өткізілді? Оның қаншасы аман жетті?

Шығарылуы:

Берілгені:

- $S = 1 \text{ км}$ (Волга ені)
- $v = 15 \text{ км/сағ}$ (қайық жылдамдығы)
- Әр қайықта 30 сарбаз
- Қайық жиілігі: 12 қайық/сағ
- Шығын: $30\% = 0,3$

1-сұрақ: Қайық өзеннің бір жағасынан екінші жағасына қанша уақытта (минутпен және секундпен) жүзеді?

Шешуі:

$$t = \frac{S}{t} = \frac{1 \text{ км}}{15 \frac{\text{км}}{\text{сағ}}} = \frac{1}{15} \text{ сағ}$$
$$\frac{1}{15} \text{ сағ} = \frac{1}{15} \cdot 60 \text{ мин} = 4 \text{ мин}$$
$$4 \text{ мин} = 4 \cdot 60 = 240 \text{ с}$$

Жауабы: 4 минут (240 секунд)

2-сұрақ: Егер әр қайық 30 сарбаз тасыса және сағатына 12 қайық өтсе, бір сағатта қанша сарбаз өткізілді?

Шешуі:

$$12 \frac{\text{қайық}}{\text{сағ}} \cdot 30 \text{ сарбаз} = 360 \frac{\text{сарбаз}}{\text{сағ}}$$

Жауабы: 360 сарбаз

3-сұрақ: Осы сарбаздардың 30%-ы өткелде қаза тапқан болса, қанша сарбаз аман жетті?

Шешуі:

$$\text{Қаза тапқаны} = 360 \cdot 0,3 = 108$$
$$\text{Аман жеткені} = 360 - 108 = 252$$

Жауабы: 252 сарбаз

4-сұрақ: Бір тәулікте (24 сағат) қанша сарбаз өткізілді?

Шешуі:

$$\text{Бір тәул өткізілгендер} = 360 \cdot 24 = 8640 \text{ сарбаз}$$
$$\text{Аман жеткені} = 8640 \cdot 0,7 = 6048 \text{ сарбаз}$$
$$\text{Қаза тапқаны} = 8640 \cdot 0,3 = 2592 \text{ сарбаз}$$

Жауабы: 8640 сарбаз өткізілді, оның 6048-і аман жетті

Педагогикалық түсініктеме: Қозғалыс формуласын пайдалана отырып, оқушы «небәрі 1 км-ден асатын өзеннен өту үшін 4 минут кеткен, бірақ әрбір 10 сарбаздың 3-і өте алмаған» деген қорытынды жасайды. Бұл – Сталинград шайқасының қаншалықты ауыр болғанын көрсетеді. Оқушыларға қосымша сұрақ: «Неліктен кешкі уақытта өткел жиірек болған?» (жауабы: қараңғылық авиациялық шабуылдардан жасыруға көмектескен).

Есеп №4. «Әйелдер мен жастар тылда» (пайыздар, диаграмма, 6–7 сынып)

Тарихи контекст: Ұлы Отан соғысы жылдарында ерлердің көпшілігі майданға алынды. Тылдағы өнеркәсіпте еңбек ететіндердің құрамы түбегейлі өзгерді.

1943 жылы КСРО-ның **әскери өнеркәсібінде** (ауыр машина жасау, танк, ұшақ, қару-жарақ зауыттары) жұмыс істейтіндердің:

- **58%** – әйелдер
- **15%** – 14–17 жас аралығындағы жасөспірімдер
- **27%** – ер адамдар (соғысқа жарамсыздар, жаралылар немесе мүгедектер)

Есептің берілуі:

1. Егер зауытта барлығы 2500 жұмысшы болса, әйелдер мен жасөспірімдер санын тап.
2. Ер адамдар неше процент және неше адам?
3. Осы мәліметтерді дөңгелек диаграммаға түсір (проценттерді градусқа айналдыр).
4. Әйелдер саны жасөспірімдер санынан неше есе артық?
5. Егер соғысқа дейін зауытта жұмысшылардың 70%- ер адамдар болса, соғыс кезінде ер адамдар саны қанша пайызға азайды?

Шығарылуы:

Берілгені:

- Барлығы = 2500 адам
- Әйелдер = 58% = 0,58
- Жасөспірімдер = 15% = 0,15
- Ер адамдар = 27% = 0,27

1-сұрақ: Егер зауытта барлығы 2500 жұмысшы болса, әйелдер мен жасөспірімдер санын тап.

Шешуі:

$$2500 \cdot 0,58 = 1450$$

$$2500 \cdot 0,15 = 375$$

Жауабы: 1450 әйел, 375 жасөспірім

2-сұрақ: Ер адамдар неше процент және неше адам?

Шешуі:

$$100\% - 58\% - 15\% = 27\%$$

$$2500 \cdot 0,27 = 675$$

Жауабы: 27% (675 адам)

3-сұрақ (дөңгелек диаграмма): Осы мәліметтерді дөңгелек диаграммаға түсір (проценттерді градусқа айналдыр)

100% = 360°, сонда 1% = 3,6°

- Әйелдер: $58 \cdot 3,6^\circ = 208,8^\circ$
- Жасөспірімдер: $15 \cdot 3,6^\circ = 54^\circ$
- Ер адамдар: $27 \cdot 3,6^\circ = 97,2^\circ$

Тексеру: $208,8^\circ + 54^\circ + 97,2^\circ = 360^\circ$

Жауабы: диаграммада 208,8° – әйелдер, 54° – жасөспірімдер, 97,2° – ер адамдар

4-сұрақ: Әйелдер саны жасөспірімдер санынан неше есе артық?

Шешуі:

$$\frac{1450}{375} \approx 3,87 \text{ есе}$$

Жауабы: Әйелдер саны жасөспірімдер санынан 3,87 есе артық

5-сұрақ (қосымша): Егер соғысқа дейін зауытта жұмысшылардың 70%- ер адамдар болса, соғыс кезінде ер адамдар саны қанша пайызға азайды?

Шешуі:

Соғысқа дейін ер адамдар = 2500 · 0,7 = 1750 адам

Соғыс кезінде ер адамдар = 675 адам

$$1750 - 675 = 1075$$

$$1750 \rightarrow 100\%$$

$$1075 \rightarrow x\%$$

$$x = \frac{1075 \cdot 100}{1750} \approx 61,4\%$$

Жауабы: Ер адамдар саны шамамен 61,4%-ға азайған

Педагогикалық

түсініктеме:

Бұл есеп арқылы оқушылар пайыздар мен диаграмманы үйреніп қана қоймай, соғыс жылдарындағы тылдағы ерлер санының азайып, әйелдер мен жасөспірімдердің

қаншалықты ауыр жүк арқалағанын көреді. Тарихи тұжырым: «Әрбір 10 тыл жұмысшысының шамамен 6-сы – әйел, 2-сі – жасөспірім, тек 2-сі ғана ер адам».

Есептерді сабақта қолданудың әдістемелік нұсқауы

3.1. Қолдану режимдері

2-кесте

Режим	Уақыты	Сипаттамасы
Фрагменттік	5–10 мин	Математика сабағында тақырыпты бекіту кезінде 1 есеп. Тарихи контекстті мұғалім қысқаша түсіндіреді.
Модульдік	20–30 мин	Арнайы «Тарих-математика» кіріктірілген сабақ. 2–3 есеп біріктіріледі.
Жобалық	1 апта	Оқушылар осы үлгілер бойынша өз бетінше жаңа есеп құрастырады.

3.2. Сыныптар бойынша бөлініс кестесі

3-кесте

Сынып	Есеп нөмірлері	Математикалық тақырыптар
5–6	№2	Бөлшектер, өлшем бірліктері, өнімділік, кесте
6–7	№1, №4	Пайыздар, диаграмма, орташа шама
7–8	№3	Қозғалыс формуласы, пропорционалдық

3.3. Интеграцияның тиімділік критерийлері

Ұсынылған есептер жүйесінің тиімділігі мынада:

1. **Уақыт үнемі** – қосымша сабақ қажет емес, негізгі математика сабағына 5–15 минут кірістіріледі.
2. **Қос нәтиже** – бір уақытта математикалық дағды мен тарихи білім бекітіледі.
3. **Мотивация** – оқушылар «құрғақ» есептерден гөрі нақты тарихи жағдаятқа қызығады.
4. **Тәрбиелік әлеует** – патриотизм сандар арқылы сезіледі.

Қорытынды

«Тарих + Математика» интеграциясын жүзеге асырудың тиімді жолдарының бірі – нақты тарихи сандық деректерге негізделген математикалық есептер. Бұл әдістің артықшылығы:

- дайын материалдарды қажет етпейді (мұғалімнің өзі құрастыра алады);
- ешбір қосымша ресурссыз, кәдімгі сабақ үстінде орындалады;
- барлық сыныптар мен барлық математикалық тақырыптарға бейімделеді.

Ұсынылып отырған есеп (Ұлы Отан соғысы тақырыбында) осы тәсілдің нақты үлгісі болып табылады. Олардың әрқайсысы:

- нақты тарихи дерекке сүйенеді;
- белгілі бір математикалық тақырыпты бекітеді;
- патриоттық тәрбие береді;
- оқушының пәнаралық байланысты түсінуіне мүмкіндік жасайды.

Бұл тәсілді басқа тарихи кезеңдерге (Ежелгі Қазақстан, Орта ғасырлар, Қазақ хандығы, тәуелсіздік кезеңі) және басқа пәндерге (география, биология) таратуға болады.

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ELT FOR NON-LINGUISTIC FACULTIES: MOTIVATIONAL AND CURRICULAR CHALLENGES IN HIGHER EDUCATION

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Abstract

This paper examines the main difficulties in teaching English to non-linguistic students in higher education. In today's globalized world, English has become an essential tool for communication in science, education, and professional contexts. However, many students still struggle to achieve an adequate level of proficiency, despite studying English at university.

The study discusses key factors affecting learning, including psychological issues such as low motivation and lack of confidence, methodological challenges like limited classroom hours and insufficient practice, and physical factors including a heavy academic workload. It also addresses issues such as first language interference, concentration problems caused by mobile phone use, and difficulties in vocabulary acquisition.

The paper emphasizes the importance of creating a supportive classroom environment and applying effective teaching methods to enhance student engagement and performance. Overall, it argues that improved teaching strategies and stronger learner motivation can significantly enhance English learning outcomes for non-linguistic students.

Keywords: *English for Specific Purposes, non-linguistic faculties, learner motivation, higher education, communicative competence, bimodal input, second language acquisition barriers*

Introduction

In today's interconnected world, English has become one of the most important means of communication across professional fields. It is widely used in science, technology, education, and international cooperation. For this reason, English is an essential part of higher education, especially for students in non-linguistic fields, who study it as a tool for professional development rather than as a philological specialization.

Despite its importance, many students still struggle to learn English effectively at university. Even though there are more digital learning opportunities than ever before, the level of English proficiency among graduates is often lower than expected. This deficit underscores deep-seated challenges in delivering functional language education within non-linguistic academic contexts (Daqiq et al., 2024; Education First [EF], 2024).

The purpose of this paper is to explore the systematic difficulties that non-linguistic students face when learning English, categorized into physical, psychological, and methodological domains. By understanding these challenges more clearly, educators can refine instructional design and help students develop the precise English communication skills required for their future careers.

Main Difficulties in Teaching English to Non-Linguistic Students

A key characteristic of a highly qualified specialist is the ability to engage in lifelong learning. In a rapidly changing world, maintaining professional competence requires continuous updating of knowledge and development of professional horizons (UNESCO, 2021). A necessary condition for this growth is proficiency in foreign languages as a means of international communication between professionals from different countries (European Commission, 2012).

English currently holds a leading position as the primary lingua franca in academic and professional contexts (Crystal, 2003). According to international linguistic research, approximately 1.49 billion people worldwide speak English, including both native and non-native speakers (Ethnologue, 2026). This means nearly 75% of the global English-speaking population consists of non-native speakers. In sociolinguistics and English Language Teaching (ELT) discourse, this is a vital statistic because it highlights that English operates primarily as a global lingua franca rather than a language bound by its native geography. It is one of the official working languages of the United Nations and holds official or co-official status in numerous countries across different continents. In many countries, English is the most commonly studied first foreign language.

In the past, English was primarily required only for language teachers and translators. However, nowadays, the goals of the education system have changed significantly, reflecting the growing demand for English as a global professional tool.

Now, English is the dominant foreign language and its teaching integrates students' professional training with access to global scientific and cultural resources, thereby enabling interaction with diverse cultures and participation in international professional communities. Thus, knowledge of English enables young specialists to become familiar with the latest research, innovations, and scientific discoveries in industry, economics, and culture, as well as to participate in international conferences, which significantly broadens their professional horizons (Crystal, 2003).

In professional environments, people who speak two or more languages are often regarded as more competitive and highly valued. In this regard, professionally oriented language teaching is one of the most important tasks of any educational institution. However, despite ongoing institutional initiatives and curriculum modernization, educational programs still yield a limited number of graduates with professional-level English proficiency. This deficit underscores deep-seated challenges in delivering functional language education within non-linguistic academic contexts (Daqiq et al., 2024; Education First [EF], 2024).

Unfortunately, even in the present day, when numerous opportunities for foreign language learning exist (private lessons, online classes with native speakers, language-learning websites, video and audio materials), not all learners achieve communicative fluency. Students encounter these difficulties at school and continue to face them at university.

The reasons may vary: lack of confidence in one's abilities, forgetting material learned at school, an inability to think in a foreign language, and difficulties in listening comprehension.

These problems require closer examination. Students often perceive a lack of confidence in their abilities as a problem rather than a genuine linguistic barrier. Students who can communicate in Azerbaijani, Turkish, or Russian can also learn English successfully, provided they receive sufficient practice and exposure (Dörnyei, 2001).

Experiences like "I learned it but forgot it" often indicate insufficient depth of learning and a lack of systematic language acquisition. It is not only enough to learn, but it is also important to achieve automaticity in language use. Mastery of collocations is also essential, as learners tend to rely on native language structures, which do not always correspond to those of the target language. Students develop the ability to think in a foreign language only through sustained practice and meaningful communication, which makes this process particularly challenging (Ellis, 2008).

Listening comprehension is also a very common problem. Even students with adequate vocabulary and grammar knowledge struggle with fluent speech because natural language involves connected and reduced forms. To address this, extensive exposure to authentic input is vital (Rost, 2011). The issue is that when confronted with fluent speech, learners fail to process meaning not because they do not recognize individual words, but because natural speech involves connected and reduced forms. Watching films with English subtitles also supports listening development by combining auditory and visual input. Utilizing bimodal input such as watching contemporary dramas or documentaries with intralingual English subtitles significantly supports listening development. This approach effectively synchronizes auditory and visual channels, optimizing vocabulary acquisition while managing the learner's cognitive load through contextualized, real-world language structures.

Another problem is that students often translate mentally from their native language into English. As a result, they speak slowly and continuously think about sentence construction. This occurs because learners first conceptualize in their native language, then attempt to retrieve equivalent lexical and grammatical structures in English.

These issues may also stem from the testing system used in higher education institutions, which requires instructors to cover a large amount of material in a limited timeframe. Although multiple-choice tests, which are worked on while preparing for university entry preparation period, include listening components, educators do not always use authentic native-speaker audio materials, which limits students' exposure to real-life language use.

Insufficient school preparation and the belief that a foreign language will not be useful in future careers further complicate the learning process for both students and teachers. Overall, there are three main categories of barriers in teaching English to non-linguistic students: physical, psychological, and methodological.

Physical, Psychological, and Methodological Difficulties

Physical difficulties:

- Teaching materials often do not fully align with students' heterogeneous proficiency levels.
- Learning environments are not always technologically or structurally conducive to effective language acquisition.
- Students have limited time for foreign language study due to heavy workloads in their core academic subjects.

Psychological difficulties:

- Low learner motivation due to anxiety or past academic friction.
- Lack of interest in the discipline, as students often perceive foreign language learning as an "unimportant," secondary subject.

Methodological difficulties:

- Lack of a natural language environment outside the classroom boundaries.
- Overemphasis on General English (GE) instead of the necessary English for Specific Purposes (ESP) tailored to professional fields.
- Insufficient number of foreign language hours in curricula for non-linguistic specialties.
- Low baseline level of students' communicative competence upon entering university.
- Perceived difficulty of foreign language acquisition, leading to early cognitive fatigue.
- Inability to apply theoretical grammar knowledge to practical communication.

The learning process must balance all four language skills—listening, speaking, reading, and writing—which are fundamental components of communicative competence (Hymes, 1972; Richards, 2006).

Insufficient language preparation of students, combined with a heavy academic workload in their major subjects, significantly limits the time they can dedicate to English learning, which negatively affects the overall quality of language proficiency.

Mismatched tasks that ignore students' actual proficiency levels frequently drive down motivation in foreign language learning. For instance, when a student fails to comprehend an authentic text, forcing them to retell it breeds cognitive frustration rather than fostering effective learning. Instructors must utilize modified elaborated input and adapt task demands to the learners' current processing capacity to ensure optimal engagement (Long, 2020; Ziegler & Bryfonski, 2022).

An objective difficulty faced by both teachers and students is the absence of a natural language environment and the presence of a language barrier. Researchers consider exposure to authentic input essential for language acquisition, particularly in contexts where learners study English as a foreign language (Ellis, 2008).

In non-linguistic disciplines, a major curriculum flaw is the overemphasis on General English (GE) at the expense of English for Specific Purposes (ESP). GE is already familiar to the majority of students, which is why it does not attract their interest. While GE provides basic communicative structures, it fails to equip students with the specialized lexicon, genre awareness, and professional discourse required in their specific fields. This misalignment leaves graduates unable to navigate technical literature or career-specific tasks, rendering generic language instruction largely ineffective for their professional needs.

When considering subjective difficulties, lack of motivation to acquire professional foreign language skills plays a significant role. Students are often convinced that they will not be able to achieve an adequate level of English within the limited time available at university, and therefore do not actively engage in learning. Motivation is widely recognized as a key factor in successful second language acquisition (Dörnyei, 2001). Therefore, forming and sustaining learner motivation is one of the central tasks of English teachers working with non-linguistic students.

It is important to note that effective teaching requires creativity. A comfortable and professional learning environment, along with modern teaching equipment, is essential; without these conditions, teachers cannot effectively organize classroom activities, maintain student engagement, or achieve the desired learning outcomes.

One of the most difficult tasks for students, especially in non-linguistic specialties, is mastering specialized vocabulary (lexical units related to specific professional fields). Many students mistakenly believe that memorizing new words is unnecessary because they rarely use these words in everyday communication. As a result, they show low motivation for vocabulary acquisition. However, vocabulary knowledge is a strong predictor of reading comprehension and overall language proficiency (Nation, 2013). Without sufficient lexical knowledge, translation becomes a cognitively demanding process that requires considerable time and effort. In such cases, overcoming lexical barriers requires the use of strategies such as electronic dictionaries, contextual inference, and guided guessing. This approach helps learners develop the ability to derive meaning from context. In spoken language, learners acquire vocabulary best through meaningful interaction and dialogue-based practice. Lexical games and communicative activities also improve retention and increase engagement in vocabulary learning.

Another important issue is first language interference, which occurs when both teachers and students frequently switch to their mother tongue during English lessons. This practice negatively affects the development of English proficiency, as reduced exposure to the target language limits acquisition and fluency development. Learners often overlook the fact that each language has its own intonation and pronunciation system, which requires consistent practice in authentic communicative settings. Therefore, teachers should consistently use English during

classroom interaction, as sustained exposure to the target language provides the optimal input necessary to trigger natural acquisition pathways (Long, 2020)."

A further disadvantage involves student concentration and attention span. Although educators often assume that students support the learning process when they use mobile phones in class solely to access electronic dictionaries or e-textbooks, students become distracted from instructional tasks when they use mobile devices for unrelated communication or social media activities, which negatively affects learning outcomes. Research has shown that multitasking with digital devices during learning reduces comprehension and retention (Sana, Weston, & Cepeda, 2013). Therefore, teachers should regulate and monitor smartphone use in the classroom when it interferes with learning activities.

Students who struggle to concentrate often get easily distracted and do not fully process learning materials. When teachers select engaging tasks and vary classroom activities dynamically, students' concentration and participation increase. At the same time, teachers should adjust the pace of instruction to match learners' abilities and needs.

It is also important to consider the subjective dimension of teacher–student relationships. The effectiveness of learning also depends on the teacher's personality and classroom interaction style. Positive teacher–student relationships increase motivation, engagement, and academic achievement (Dörnyei, 2001). When students respect and connect positively with their teacher, they are more willing to participate and engage actively in classroom activities. Although this applies to all academic disciplines, the subjective factor plays a particularly significant role in practical language classes.

Teachers should consistently apply a range of strategies to motivate students and encourage active participation in order to overcome barriers in foreign language learning. However, many students continue to have trouble, and not all are able to overcome these challenges independently. Therefore, identifying the factors that hinder success in English classes remains an important pedagogical task, as each issue requires an appropriate instructional response.

Conclusion

Teaching English to non-linguistic students is a complex process shaped by academic, psychological, and practical factors. Although English serves as an essential tool for professional communication, limited classroom hours, heavy core workloads, and a lack of a natural language environment complicate its mastery.

Psychological barriers restrict learning just as much as academic ones. Many students treat English as a secondary subject, and low confidence or a fear of mistakes slows their progress. These issues are further compounded by modern challenges, such as digital distractions, first-language interference, and a curricular overemphasis on General English rather than field-specific ESP.

To overcome these barriers, higher education programs must adopt a balanced approach that transforms both teaching practices and learner attitudes. In this context, the teacher plays a central role. Teachers enhance students' motivation and performance by adopting a supportive and engaging approach, designing clear tasks, encouraging active classroom interaction, and applying modern teaching methods. When teachers structure lessons well and make them interactive, students become more involved and participate more willingly.

Overall, improving English instruction for non-linguistic students requires a balanced approach that considers both teaching practices and learner attitudes. When educators address these challenges effectively, students strengthen their language skills and become better prepared for international academic and professional environments.

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Revolutionizing English Language Teaching in Kazakhstan Universities: The Transformative Role of AI Tools in the Classroom

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In Kazakhstan's universities, English language teaching (ELT) stands at a pivotal crossroads. The country's ambitious trilingual education policy—promoting Kazakh, Russian, and English as languages of instruction—has elevated English proficiency as a national priority for global competitiveness, academic publishing, and international collaboration. Yet, challenges persist: varying student proficiency levels, large class sizes, limited exposure to authentic English environments, and teacher workloads strained by traditional methods. Enter artificial intelligence (AI). With Kazakhstan's government investing heavily through the Concept for the Development of Artificial Intelligence (2024–2029), including AI literacy courses and infrastructure upgrades at leading institutions like Al-Farabi Kazakh National University, L.N. Gumilyov Eurasian National University, Satbayev University, and Abai Kazakh National Pedagogical University, AI tools are no longer futuristic—they are practical allies in the ELT classroom. This article explores how AI is reshaping English language learning in Kazakh higher education, highlighting key tools, benefits, challenges, and actionable recommendations for educators and administrators.

Why AI Matters for ELT in Kazakhstan

Kazakhstan's higher education system serves a diverse student body, many of whom balance English with Kazakh and Russian. Traditional ELT often relies on rote memorization, limited speaking practice, and one-size-fits-all materials—approaches that struggle to address individual needs in large lecture halls or amid varying digital access between urban centers like Almaty and Astana and more remote regions.

Recent studies, including experiments at Abai University, show that AI-enhanced instruction can significantly improve outcomes compared to traditional methods. Nationally, AI is being integrated not just for efficiency but for equity: personalized pathways help bridge proficiency gaps, while teacher-support tools free educators to focus on mentorship and critical thinking. As one 2026 analysis noted, AI-driven personalized tutoring and adaptive learning rank among the top uses of the technology in education globally—and Kazakhstan is actively positioning itself as a regional leader.

Key AI Tools Transforming the ELT Classroom

AI tools fall into several categories that directly support the four language skills (listening, speaking, reading, writing) while aligning with Universal Design for Learning principles—offering multiple means of engagement, representation, and expression.

1. Personalized Conversation Practice and Tutoring

Tools like **ChatGPT**, **Google Gemini**, and **Claude** act as on-demand language partners. Students can engage in role-plays, debate current events, or receive instant feedback on grammar and vocabulary. In Kazakh universities, where authentic speaking opportunities are scarce, these chatbots simulate real conversations 24/7.

Emerging platforms such as **Langua** and **Duolingo Max** (with GPT-powered features) offer voice-cloned native speakers and adaptive dialogue, making practice feel immersive. A student preparing for an IELTS speaking test, for example, can rehearse with AI that remembers prior mistakes and builds targeted exercises.

2. Pronunciation and Speaking Feedback

ELSA Speak and similar speech-recognition tools analyze pronunciation in real time, providing visual feedback on intonation, stress, and accents—crucial for Kazakh learners whose first languages may influence English phonetics. These apps adapt to individual progress, turning speaking anxiety into measurable improvement. Teachers report using them for flipped classrooms: students practice independently, then discuss results in class.

3. Writing Assistance and Automated Feedback

Grammarly (with AI enhancements) and ChatGPT excel here. Students draft essays in English, receive suggestions on structure, vocabulary, and academic tone, then revise iteratively. For instructors, tools like **CoGrader** or AI-powered rubrics handle initial grading, highlighting common errors across a cohort while flagging plagiarism. This is especially valuable in large classes where manual feedback is time-intensive.

Specialized platforms like Twee (designed for language teachers) generate differentiated writing prompts, rubrics, or even full lesson plans tailored to CEFR levels common in Kazakh programs.

4. Lesson Planning, Materials Creation, and Assessment

AI streamlines preparation: **Diffit** adapts reading texts to different proficiency levels; **Gamma** creates visually engaging presentations; and text-to-speech tools (e.g., Google's or ElevenLabs) produce listening materials with natural voices in multiple accents. For assessment, AI can generate quizzes, analyze speaking recordings, or provide formative insights—freeing teachers for higher-value interactions.

5. Inclusive Supports

AI also advances accessibility. Speech-to-text and text-to-speech features help students with motor or learning differences participate fully. Personalized adaptive paths align with Kazakhstan's push for inclusive education, ensuring no learner is left behind.

Benefits for Kazakh Universities

The advantages are clear and evidence-based. AI personalizes learning at scale—addressing the wide proficiency range in first-year EFL courses. Teachers save hours on routine tasks (lesson planning, grading), allowing more time for cultural context, critical literacy, and student motivation. Early pilots in Kazakhstan show improved engagement, faster skill gains, and higher student confidence. On a systemic level, AI supports the trilingual policy by making English more approachable without replacing human instructors. It also prepares graduates for an AI-driven job market, where digital literacy is as vital as language skills.

Challenges and Ethical Considerations

Adoption is not without hurdles. Kazakhstan ranks respectably in global AI readiness but faces a digital divide: unreliable internet in rural areas limits consistent use. Teacher readiness varies—surveys of EFL instructors reveal lower confidence in ethical AI integration, including issues of academic integrity, data privacy, and over-reliance that could hinder deep learning.

AI tools, trained largely on Western English data, may carry cultural biases or struggle with Kazakh-specific contexts. Ethical questions abound: How do we detect AI-generated work fairly? How do we protect student data under national regulations? And how do we ensure AI complements, rather than replaces, the human element central to language teaching?

Recommendations for Successful Integration

To harness AI effectively in Kazakh university ELT classrooms:

Invest in Targeted Training: Expand professional development programs (building on existing ICHEI and national initiatives) to focus on practical AI pedagogy, ethical use, and prompt engineering for language tasks.

Adopt a Hybrid Model: Use AI for practice and personalization; reserve classroom time for collaborative, creative, and culturally relevant activities.

Address Equity: Prioritize offline-capable tools or low-bandwidth options and provide device access where needed. Pilot programs in mixed urban-rural settings.

Develop Institutional Policies: Create clear guidelines on AI use, citation, and assessment—many universities worldwide have already done so successfully.

Collaborate and Research: Partner with tech firms (e.g., via Satbayev’s AI-Sana initiatives) and conduct local studies on AI’s impact on ELT outcomes.

As Kazakhstan accelerates its AI journey—joining global initiatives like OpenAI’s Education for Countries and building computational clusters at top universities—the future of ELT is bright. AI tools are not a silver bullet, but when implemented thoughtfully, they can democratize high-quality English education, boost proficiency, and position Kazakh graduates as globally competitive professionals. The real revolution lies not in the technology itself, but in how educators and institutions choose to wield it: as a powerful assistant that amplifies human potential rather than diminishing it. For Kazakhstan’s universities, embracing AI in the English classroom is more than an upgrade—it is a strategic step toward a more inclusive, innovative, and internationally connected higher education system.

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GENERATIVE AI AS AN EXTENSION OF POSTMODERN AESTHETICS: DECONSTRUCTION AND AUTOMATION IN CONTEMPORARY VISUAL MEDIA

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Abstract

This article examines generative artificial intelligence as an aesthetic phenomenon, arguing that the image- and media-generating systems that have proliferated since the late 2010s constitute not a rupture with the history of visual culture but an extension and intensification of the aesthetic logic of postmodernism. Where postmodern theory described a culture defined by pastiche, simulation, intertextuality, the collapse of the distinction between original and copy, and the displacement of the author as the origin of meaning, generative models built on adversarial and diffusion architectures appear to automate and operationalise precisely these conditions. The research traces the conceptual lineage connecting the post-structuralist and postmodern theory of Roland Barthes, Jacques Derrida, Jean Baudrillard, and Fredric Jameson to the technical operation of contemporary generative systems, and analyses how core postmodern strategies — deconstruction, citation, the dissolution of the aura, and the rejection of the singular author — are materialised in machine-generated visual media. A conceptual and media-theoretical analysis framework, presented as a systematic mapping of postmodern concepts to their generative analogues, is applied alongside comparative case study analysis of four paradigmatic generative art works by Refik Anadol, Mario Klingemann, and Anna Ridler, enabling identification of the specific ways in which automation both extends and transforms the postmodern aesthetic inheritance. Critical perspectives that contest the postmodern thesis, including Lev Manovich's data realism framework and arguments for the persistence of authorship, are examined alongside the main argument. The article gives particular attention to the Azerbaijani design context, examining how the structural underrepresentation of non-Western visual cultures in generative training data intersects with the specific conditions of post-Soviet aesthetic transition and emergent local generative practice. Implications for visual practitioners, design educators, and cultural theorists are discussed.

Keywords: *Generative Artificial Intelligence, Postmodern Aesthetics, Deconstruction, Automation, Visual Media, Simulation, Authorship.*

JEL Codes: Z11, L82, O33

1. Introduction

The rapid emergence of generative artificial intelligence as a tool of cultural production represents one of the most consequential developments in the recent history of visual media. Within the space of a few years, systems capable of synthesising photorealistic images, moving images, and graphic compositions directly from textual description have moved from research laboratories into the everyday practice of designers, artists, advertisers, and ordinary users of social media. The cultural and economic implications of this transformation are the subject of intense and often polarised debate, much of which frames generative AI as an unprecedented

break — a technological rupture that severs contemporary visual culture from everything that preceded it.

This article advances a different argument. It proposes that generative AI, considered as an aesthetic phenomenon, is most productively understood not as a rupture but as an extension and intensification of the aesthetic logic of postmodernism. The conceptual vocabulary developed by postmodern and post-structuralist theorists over the second half of the twentieth century — pastiche, simulation, intertextuality, deconstruction, the death of the author, the collapse of the distinction between original and copy — describes with remarkable precision the conditions that generative systems now automate and operationalise. What postmodern theory identified as the cultural condition of late modernity, generative AI appears to render as a technical procedure embedded in the production of images themselves.

The relationship between generative AI and postmodern aesthetics is not merely analogical. The two are connected by a shared underlying logic of reproduction, recombination, and citation. Postmodern cultural production, as theorised by figures including Fredric Jameson and Jean Baudrillard, was characterised by the exhaustion of stylistic novelty and the turn towards the recombination of existing cultural materials; generative models, trained on vast archives of existing images and texts, are recombinatory engines by their very architecture. They do not invent *ex nihilo* but interpolate within a statistical space derived from the totality of their training data — a procedure that materialises, at scale and at speed, the postmodern condition of belated, citational creativity.

This article investigates how the defining strategies of postmodern aesthetics are extended, automated, and transformed by generative AI in contemporary visual media. It traces the theoretical lineage connecting postmodern thought to the operation of generative systems, presents a systematic analytical framework, analyses the deconstructive and citational operations embedded in generative architectures, and conducts comparative case study analysis of four paradigmatic generative art works. It also examines critical perspectives that contest the postmodern thesis, considers the broader field of contemporary visual media, and expands at length on the specific conditions of the Azerbaijani design context. The analysis draws on media theory, postmodern cultural theory, the emerging critical literature on artificial intelligence and visual culture, and primary material from generative art practice.

2. Theoretical Foundations: Postmodern Aesthetics and the Logic of Reproduction

To establish the connection between generative AI and postmodern aesthetics, it is necessary to recall the central tenets of postmodern aesthetic theory. Postmodernism, understood as a description of a cultural condition rather than a unified movement, emerged in the latter decades of the twentieth century as a response to the perceived exhaustion of modernist ideals of originality, progress, and authentic expression. Where modernism had valorised the new, the original, and the autonomous creative subject, postmodern theory described a culture in which these values had become increasingly untenable.

Fredric Jameson's analysis of postmodernism as the cultural logic of late capitalism provides one of the most influential frameworks for understanding this shift. Jameson identified pastiche — the imitation of past styles without the satirical impulse of parody — as the characteristic aesthetic mode of postmodern culture. In a cultural situation in which all available styles appear already to have been invented, artistic production becomes a matter of recombining and citing existing stylistic codes rather than generating genuinely new forms. This waning of historical novelty and the turn towards stylistic recombination describe with uncanny accuracy the operation of generative systems, which produce outputs by recombining learned stylistic features rather than by originating new aesthetic languages.

Jean Baudrillard's theory of simulation and the simulacrum offers a second foundational framework. Baudrillard argued that contemporary culture had entered a condition of hyperreality, in which signs and images no longer refer to any external reality but only to other signs. The simulacrum — a copy without an original — became, in Baudrillard's analysis, the characteristic object of postmodern culture. Generative AI produces precisely such simulacra: synthetic images that refer to no real referent and that are generated entirely from the statistical patterns of prior images. The generative image is a simulacrum in the Baudrillardian sense: a copy whose original never existed.

Roland Barthes' essay on the death of the author provides a third foundational text. Barthes argued that the meaning of a text is not determined by the intentions of its author but is produced in the act of reading, and that the figure of the author as origin and guarantor of meaning is a historically contingent construction. The text is, for Barthes, a tissue of quotations drawn from the innumerable centres of culture, a site where pre-existing codes are woven together rather than an expression of individual creative intention. This conception of production as the recombination of existing codes, rather than the expression of an originating subject, anticipates with striking precision the operation of generative models.

Walter Benjamin's earlier analysis of mechanical reproduction supplies an essential historical frame. Benjamin argued that the technologies of mechanical reproduction destroyed the aura of the work of art, its unique presence in time and space, transforming the cultural function of the image. Generative AI extends this process to its logical conclusion: where mechanical reproduction multiplied copies of an existing original, generative production dispenses with the original altogether, synthesising images that are copies of nothing. Finally, Jacques Derrida's concept of deconstruction, and his associated notion of *différance*, provide the theoretical vocabulary for understanding operations performed within generative systems: the latent space, in which images are decomposed into recombinable features and meaning is produced through interpolation and difference, can be understood as a technical instantiation of the Derridean play of differences.

3. Methodology

This study employs a qualitative conceptual analysis approach, combining media-theoretical analysis of generative systems with systematic comparative case study analysis of selected artistic works. The analytical framework integrates three methodological strands: theoretical-genealogical analysis, which traces the conceptual lineage connecting postmodern aesthetic theory to the operation of generative systems; technical-conceptual analysis, which examines how the architecture and operation of generative models instantiate aesthetic principles; and critical-practical analysis, which applies the derived framework to specific works and considers critical perspectives that contest the principal thesis.

Table 1 presents the full analytical framework applied in this study, mapping the principal postmodern aesthetic concepts to their theoretical sources and their identified generative AI analogues. This framework is used as the analytical basis for both the deconstructive and authorship sections (Sections 4 and 5) and the case study analyses (Section 7). The framework does not claim that the relationship between each postmodern concept and its generative analogue is one of identity; rather, it argues for structural and operational homology — a shared logical form that justifies treating generative production as the technical operationalisation, rather than the mere metaphorical equivalent, of postmodern aesthetic principles.

Table 1. Analytical framework mapping postmodern aesthetic concepts to generative AI operations

Postmodern Concept	Theorist	Core Principle	Generative AI Analogue
Pastiche	Jameson (1991)	Stylistic recombination without satirical intent; exhaustion of historical novelty	Style-conditioned generation; 'in the style of' prompting; model fine-tuning
Simulacrum / Hyperreality	Baudrillard (1994)	Copy without original; sign systems referring only to other signs; collapse of the real–representation distinction	Photorealistic synthesis with no referent; deepfake production; originless image generation
Death of the Author	Barthes (1977)	Meaning produced in reading, not by authorial intention; text as tissue of cultural quotations	Prompt-driven generation; distributed authorship across model, trainer, prompter; intertextual training corpus
Deconstruction / Différance	Derrida (1976)	Meaning as endless deferral through difference; dismantling of stable textual structures	Latent space decomposition; interpolation between image representations; no stable image identity
Loss of the Aura	Benjamin (2008)	Mechanical reproduction destroys the unique presence and authenticity of the original work	Generative synthesis produces images with no auratic origin; copy structurally precedes original
Intertextuality	Barthes (1977)	Every text constituted by traces of prior texts; meaning emerges from web of cultural references	Training corpus as exhaustive intertext; every output recombines abstracted features of prior works
Irony / Self-reflexivity	Hutcheon (1989)	Critical distance from representational conventions; foregrounding of the constructed status of the artefact	Glitch and artifact aesthetics; deliberate foregrounding of synthetic origin; reflexive AI art practice

The technical systems examined include the principal architectures that have driven the generative turn in visual media: generative adversarial networks, introduced by Goodfellow and colleagues in 2014, and latent diffusion models, exemplified by the Stable Diffusion architecture introduced by Rombach and colleagues in 2022. These architectures are examined at the level of their aesthetic and conceptual operation — the ways in which they decompose, recombine, and synthesise visual material — rather than at the level of mathematical detail.

The corpus for case study analysis was selected to represent diversity of generative approaches, institutional contexts, and positions with respect to the principal thesis. Selection criteria prioritised works with documented scholarly or critical reception, works that employ distinct generative architectures, and works that illuminate both the postmodern aesthetic thesis and its critical limits. The four works examined are: Refik Anadol’s *Machine Hallucinations* (2019)

and Unsupervised (2022), Mario Klingemann's *Memories of Passersby I* (2018), and Anna Ridler's *Mosaic Virus* (2018–2019).

4. Deconstructive Operations in Generative AI

4.1 The Latent Space as a Field of Deconstruction

The latent space is the conceptual and technical heart of contemporary generative systems, and it is also the site at which the deconstructive logic of generative production is most clearly visible. In a generative model, the latent space is a high-dimensional mathematical space in which the features of the training data are represented in compressed, abstracted form. Images are not stored in this space as discrete pictures but are dissolved into distributions of features — edges, textures, colours, shapes, and higher-order combinations — from which new images can be synthesised through sampling and interpolation.

This decomposition of the image into recombinable features enacts, in technical form, the deconstructive operation that postmodern artists and designers pursued by manual means. Where the deconstructive designer dismantled the conventional structures of the image to expose their constructed character and to open them to recombination, the generative model performs this dismantling automatically and at the level of statistical abstraction. The image, in the latent space, has no integrity as a unified representation; it exists only as a point in a continuous space of possible recombinations, surrounded by infinitely many neighbouring images into which it can be smoothly transformed.

The practice of latent space interpolation — generating sequences of images that morph continuously between two points in the latent space — makes this deconstructive condition visible. Such interpolations reveal that there is no stable boundary between distinct images, no fixed identity that resists transformation, only a continuous field of difference across which forms flow into one another. This is a precise visual instantiation of the Derridean conception of meaning as the play of difference, in which no term is fully self-identical but is constituted only through its differential relations to other terms.

A note of caution is warranted here. The Derridean concept of deconstruction involves a critical reflexivity — an awareness of the operations being performed and their implications for the stability of meaning — that generative systems do not possess. When a postmodern designer deconstructs a text, the act is intentional and self-aware; when a generative model decomposes an image into latent features, there is no awareness, no critical intent. The structural homology between deconstruction and latent decomposition is genuine, but it does not make the generative system a deconstructive agent in the full philosophical sense.

4.2 Pastiche, Style Transfer, and the Automation of Citation

If pastiche is the characteristic aesthetic mode of postmodern culture, as Jameson argued, then generative AI is the apparatus of its automation. The capacity of generative models to produce images in the style of a named artist, movement, or period — to synthesise an image bearing the visual characteristics of Impressionism, of a particular photographer, or of a recognisable graphic tradition — constitutes the technical realisation of pastiche as an operationalised procedure. The user specifies a stylistic code; the model recombines the features associated with that code to produce a new instance that cites the style without belonging to its historical moment.

This automation of citation has profound consequences for the postmodern aesthetic of historical recombination. Where the postmodern artist or designer engaged in citation as a deliberate, laborious, and selective practice — choosing references, combining them with critical or ironic intent, and bearing the marks of individual judgement — the generative model performs

citation as a frictionless, instantaneous, and exhaustive operation. Every output is a pastiche, a recombination of cited stylistic features, but the citation is performed without deliberation, without irony, and without the selective intelligence that characterised postmodern citational practice. The result might be termed pastiche degree zero: citation evacuated of the critical and selective dimension that distinguished postmodern recombination from mere stylistic reproduction.

The technique of style transfer, in which the stylistic features of one image are applied to the content of another, makes this operation explicit. Style transfer treats style as a detachable, transferable quality — a set of features that can be extracted from any image and applied to any other — and in doing so it confirms the postmodern intuition that style is a code rather than an essence. The generative model does not possess a style of its own; it has access to all styles as equally available, equally citable codes, recombining them without the selective awareness that gives postmodern citation its critical force.

4.3 The Dissolution of the Original and the Aura

The generative image poses in acute form the question of the original that has preoccupied aesthetic theory since Benjamin. A photograph, however widely reproduced, refers to an original scene that existed before the camera; a printed reproduction of a painting refers to an original painting that exists somewhere. The generative image refers to no such original. It is synthesised from the statistical patterns of a training corpus, depicting a scene that never occurred, assembled from features abstracted from millions of prior images. It is, in Baudrillard's terms, a pure simulacrum — a copy without an original, a representation with no referent.

This dissolution of the original carries Benjamin's analysis of the aura to its terminus. Benjamin argued that mechanical reproduction stripped the work of art of its aura, its unique presence in time and space, by multiplying copies that could be encountered anywhere and everywhere. But the mechanically reproduced image still referred to an auratic original, however distant. The generative image has no auratic origin to lose, because it never possessed an original presence. It is born as reproduction, a copy that precedes and dispenses with any original. The aura is not destroyed but rendered structurally impossible.

Boris Groys (2008) has proposed a significant counter-argument to this position. Groys contends that in the digital era, copying does not destroy aura but can produce it: the unique specification of a generative prompt, resulting in a singular output, may itself constitute a form of singular presence in the digital flow of images. The auction sale of Mario Klingemann's *Memories of Passersby I* (2018) — a generative machine that produces faces endlessly and without repetition — as a unique art object at Sotheby's in 2019 illustrates this paradox: the machine that produces infinite, authorless images was itself sold as an auratic, singular object. This reversal of Benjamin's analysis does not refute the simulacrum condition of the individual generated image but it indicates that the institutional and commercial systems of art are developing mechanisms to relocate aura within the generative apparatus itself.

4.4 The Glitch, the Artifact, and the Aesthetics of Imperfection

The characteristic visual artifacts of generative production — the malformed hands, the impossible architectures, the melting and merging of forms, the uncanny distortions that betray the synthetic origin of an image — have given rise to a distinctive aesthetic that extends the postmodern embrace of imperfection, error, and the visible marks of mediation. Where modernist aesthetics pursued seamless perfection and the effacement of the production process, postmodern practice often foregrounded the glitch, the seam, and the artifact as means of exposing the constructed character of the image and resisting the illusion of transparent representation.

The artifacts of generative production perform a similar function, though without deliberate intent. The distorted hand or the impossible reflection reveals the image as a synthetic construction, a statistical artifact rather than a window onto reality, and in doing so enacts the postmodern critique of representational transparency. A growing body of artistic practice has embraced these artifacts deliberately, cultivating the characteristic distortions of generative production as an aesthetic resource and foregrounding the synthetic, computational origin of the image rather than concealing it.

This embrace of the generative artifact connects to a longer lineage of glitch aesthetics in digital art, in which the malfunction and the breakdown of the technical system are valued as moments at which the invisible operation of the medium becomes perceptible. The generative artifact is a glitch in this sense: a point at which the statistical machinery of synthesis reveals itself as machinery. In foregrounding these moments, generative art practice extends the postmodern project of rendering the medium visible and contesting the illusion of unmediated representation.

5. Automation and the Reconfiguration of Authorship

5.1 The Death of the Author and the Birth of the Prompter

Barthes' announcement of the death of the author finds an unexpected literalisation in generative production. The generative image has no author in the conventional sense — no individual creative subject whose intentions and skills are expressed in the work. The image is produced by a model trained on the work of countless prior creators, none of whom can claim authorship of any particular output, in response to a prompt supplied by a user who has not made the image in any traditional sense. The originating subject that Barthes sought to displace is, in generative production, genuinely absent.

In place of the author, generative production installs a new figure: the prompter, whose creative agency consists not in the making of the image but in the specification of the textual description from which the model synthesises it. The emergence of prompt engineering as a recognised practice — the development of skill in composing textual prompts that elicit desired outputs — represents the reconstitution of creative agency around the act of specification rather than the act of making. The prompter does not draw, paint, or photograph; the prompter describes, and the model executes. This redistribution of creative agency realises, in concrete institutional and technical form, the dispersal of authorship that postmodern theory described.

5.2 Intertextuality at Scale

Intertextuality — the condition of every text carrying within it traces of other texts — is, in generative production, not merely a property of the finished work but the very principle of its construction. The generative model is trained on a corpus comprising millions or billions of images and texts, and every output it produces is a recombination of patterns abstracted from this corpus. The generative image is intertextual in the most literal and exhaustive sense: it is woven entirely from the traces of prior images, with no thread that does not derive from the training data. The tissue of quotations that Barthes saw in every text becomes, in the generative image, the entire fabric.

The political and ethical implications of this condition have become the subject of intense contestation. The training of generative models on vast corpora of existing creative work, frequently gathered without the consent or compensation of the original creators, has provoked widespread concern about the appropriation of creative labour. Legal actions including *Getty Images v. Stability AI* (2023) and *Andersen v. Stability AI* (2023) reflect a cultural and legal insistence on treating the training corpus not as an anonymous intertext but as a collection of individually authored works. The intertextuality that postmodern theory celebrated as a liberation

from the myth of originality reappears, in the generative context, as a mechanism of appropriation, raising questions about the relationship between the recombinatory aesthetics of postmodernism and the economic conditions of cultural production that postmodern theory often left unexamined.

5.3 Simulation, Hyperreality, and the Synthetic Image

The proliferation of synthetic images indistinguishable from photographs realises Baudrillard's hyperreality as a pervasive condition of contemporary visual culture. When images depicting events that never occurred and persons who never existed circulate alongside documentary images, and when the two become perceptually indistinguishable, the relationship between the image and reality that grounded the documentary tradition is fundamentally destabilised. The synthetic image does not lie about reality so much as dispense with reality as a referent altogether, producing a hyperreal visual environment in which the question of what is real becomes increasingly difficult to pose.

The phenomenon of the deepfake — the synthetic manipulation of images and video to depict real persons saying or doing things they never said or did — represents the most acute manifestation of this condition. The deepfake is a simulacrum that masquerades as documentation, borrowing the evidentiary authority of the photograph while severing the connection to reality on which that authority depended. The widespread anxiety provoked by deepfakes reflects a recognition that the photographic regime of truth — the assumption that an image documents a reality that existed before the camera — has been rendered untenable by generative synthesis. This condition extends and intensifies the postmodern destabilisation of the real that Baudrillard described, but it also introduces political and epistemic dangers that the playful postmodern celebration of the simulacrum was not equipped to address.

6. Critical Perspectives and Alternative Frameworks

6.1 Data Realism and the Limits of the Postmodern Analogy

The most substantial challenge to the postmodern thesis advanced in this article comes from Lev Manovich's concept of 'data realism', developed in his work on AI aesthetics. Manovich argues that AI does not operate through irony, historical self-consciousness, or the deliberate citation that defines postmodern aesthetics; rather, it operates through statistical averaging, which produces something closer to a probabilistic representation of existing visual culture than to a critically reflexive recombination of its codes. The generative model's outputs are not pastiche in Jameson's sense, because pastiche implies a knowing relationship to the styles being imitated; the model is indifferent to the cultural meaning of the styles it recombines, treating Baroque painting, Instagram photography, and Soviet propaganda posters as equally weighted statistical samples in the same training distribution.

This distinction matters for the broader argument. Postmodernism is characterised not only by the structural condition of recombination but by a reflexive awareness of its own citational condition — an ironic self-consciousness that Hutcheon (1989) identifies as the defining rhetorical mode of postmodern cultural production. Generative systems have no such self-consciousness; they do not cite ironically but recombine statistically. Manovich's critique suggests that the postmodern framework may be a productive heuristic for understanding the cultural effects of generative AI without being fully adequate to the technical conditions of its production. Generative AI may extend postmodern aesthetics at the level of cultural output while operating by a fundamentally different logic at the level of production.

A further challenge comes from the concept of the post-digital, developed by Florian Cramer (2014). Cramer argues that the opposition between analogue and digital, original and

reproduction, human and machine production that structured both modernist and postmodern cultural theory has been rendered obsolete; the post-digital condition is not one in which these oppositions are deconstructed or played with, but one in which they have ceased to organise cultural experience at all. In this framework, generative AI may represent not the culmination of postmodernism but its historical supersession: a condition in which the postmodern game of citations and simulations has been automated to the point of invisibility, and in which the critical reflexivity on which postmodernism depended is no longer structurally available.

6.2 The Persistence of Authorship and Legal Contestation

The legal contestation of generative AI has produced a striking practical counter-argument to the death of the author. Legal actions brought by artists and copyright holders against developers of generative systems — including Getty Images' suit against Stability AI and the class action brought by visual artists including Sarah Andersen and Kelly McKernan — insist that the training corpus constitutes a collection of individually authored works rather than an anonymous intertext. In these legal framings, the death of the author is not only philosophically premature but legally impermissible: the law continues to recognise individual creative labour as the origin of protected expression, and the use of that labour to train generative systems without consent or compensation is treated as a form of appropriation.

Aaron Hertzmann's (2018) philosophical argument that computers cannot create art in the full sense — that generative systems function as media through which human creative agency operates, rather than as autonomous creative agents — offers a further challenge to the death-of-the-author argument. On this account, the prompter's agency, however transformed, constitutes a form of authorship, and the generative system is better understood as a highly sophisticated instrument than as an autonomous producer. The emergence of prompt engineering as a professional practice, and the legal recognition of prompt authorship in some jurisdictions, suggests that the death of the author in generative production may be less thoroughgoing than the postmodern thesis implies.

6.3 Post-Digital and Synthetic Realism as Competing Frameworks

Beyond the data realism and post-digital frameworks, a further alternative is what might be called synthetic realism: the observation that photorealistic generative images, despite their lack of a real referent, function culturally as representations of reality. Viewers routinely mistake synthetic images for photographs, and the cultural authority attached to photographic images is in practice transferred to synthetic ones, even in the absence of the evidentiary connection that grounds that authority. This suggests not the Baudrillardian condition of hyperreality — a condition of liberated simulation in which the distinction between representation and reality collapses playfully — but a condition of systematic epistemic destabilisation in which the cultural machinery of documentary truth continues to function even as its technical preconditions are dissolved.

These competing frameworks do not refute the postmodern thesis but indicate its limits. The argument advanced in this article is not that generative AI is postmodern in all respects, but that the postmodern conceptual vocabulary provides the most productive available framework for understanding its aesthetic dimensions. Recognising the limitations of this framework — the absence of reflexivity, the statistical rather than ironic character of recombination, the legal and cultural persistence of authorship, and the specific dangers introduced by epistemic destabilisation — is essential to its responsible application.

7. Case Study Analysis: Selected Generative Art Works

7.1 Selection Criteria and Analytical Framework

The four works examined in this section were selected to represent diversity of generative architectures, institutional contexts, artistic approaches, and positions with respect to the principal thesis. *Machine Hallucinations* (2019) and *Unsupervised* (2022) by Refik Anadol represent large-scale institutional generative work that enacts the simulation and intertextuality theses while raising questions about spectacularisation. *Memories of Passersby I* (2018) by Mario Klingemann represents a critical engagement with authorship and the portrait tradition. *Mosaic Virus* (2018–2019) by Anna Ridler represents a methodologically distinctive practice that directly addresses the opacity of training data and reasserts human curatorial labour within the generative process. Table 2 summarises the principal analytical dimensions of each work.

Table 2. Comparative case study analysis of selected generative art works

Artist	Work	Year	Primary Postmodern Strategy	Critical Note
Refik Anadol	<i>Machine Hallucinations</i>	2019	Simulation/sublime: urban image database rendered as generative latent environment; hyperreal data visualisation	Criticised for aestheticising computation without interrogating conditions of data collection (Zylinska, 2020)
Refik Anadol	<i>Unsupervised</i>	2022	Intertextuality at institutional scale: MoMA’s archive as generative corpus; art history as latent space	Institutional deployment at MoMA reproduces canonical authority even as it formally contests hierarchies
Mario Klingemann	<i>Memories of Passersby I</i>	2018	Death of the Author: infinite portrait generation with no singular subject; faces derived from art-historical corpus	Sold at auction as unique ‘machine’ object, paradoxically reasserting auratic singularity of the apparatus
Anna Ridler	<i>Mosaic Virus</i>	2018–2019	Pastiche/intertextuality with explicit labour: curated dataset of 10,000 personally photographed tulips; outputs linked to bitcoin price	Directly contests training data opacity; reasserts human curatorial labour within generative process

7.2 Refik Anadol: *Machine Hallucinations* (2019) and *Unsupervised* (2022)

Machine Hallucinations was first exhibited as a large-scale public installation in New York’s Times Square in 2019. The work processes a dataset of approximately 200 million publicly available

images of New York's urban environment, using a custom deep learning architecture to generate a continuously evolving visual field that the artist describes as the machine's 'dream' of the city it has learned. The result is a luminous, abstract flux of colour, texture, and form in which architectural and urban elements are visible but constantly dissolving and reforming, held in a permanent state of latent recombination.

From the analytical framework of Table 1, *Machine Hallucinations* enacts simulation in the Baudrillardian sense: the city exists in the work not as representation but as data, and the output bears no indexical relationship to any specific moment or location in New York. It is a pure simulacrum of the urban environment, generated from its statistical regularities rather than from any particular scene. At the same time, the work enacts the latent space as a field of deconstruction: the urban image is dismantled into its constituent features and held in a state of perpetual recombination, with no stable image identity persisting between one moment and the next. The immersive scale of the installation — designed for public space and large institutional environments — produces what might be described as a generative sublime, overwhelming the viewer with the visual evidence of data processed at scales that exceed human imaginative capacity.

Unsupervised, exhibited at the Museum of Modern Art in New York from November 2022 to March 2023, extends this approach to the domain of art history. The work trains a custom generative model on approximately 200 years of the works in MoMA's permanent collection, producing outputs that respond in real-time to the presence and movement of visitors in the gallery. The postmodern dimension of the work is unusually explicit: the museum's canonical collection — the institutionalised, hierarchical archive of Western modern art — becomes the latent space from which the generative system synthesises new visual material that is continuous with, yet radically different from, the works it has learned. Art history is treated as a statistical distribution to be sampled rather than as a canon to be reproduced or contested.

The critical reception of Anadol's work has been divided. Sympathetic accounts emphasise its capacity to render data as sensory experience, making visible the computational infrastructure that shapes contemporary visual culture (Zylinska, 2020). Critical accounts, including those associated with socially engaged AI art practice, question whether the work's spectacular visual qualities serve to aestheticise computation and institutional authority rather than to interrogate either. The deployment of *Unsupervised* within MoMA is particularly complex: the institutional aura of the museum is not dissolved by the generative work but transferred to it, positioning the simulated outputs within a framework of canonical cultural authority that the postmodern formal strategy might seem to contest. This tension — between the formal logic of the work and its institutional context — illustrates the limits of reading generative art practice through an exclusively aesthetic framework, and suggests the necessity of the critical perspective developed in Section 6.

7.3 Mario Klingemann: *Memories of Passersby I* (2018)

Memories of Passersby I is a self-contained generative installation consisting of two opposing screens on which a continuously operating GAN network, trained on historical portrait paintings, generates an unending stream of faces: human physiognomies that have never existed, derived from the statistical patterns of centuries of portraiture. The faces are technically convincing, occupying the visual register of old master painting, yet belong to no historical subject and express no personality, memory, or identity. The installation operates without human intervention; once activated, it continues generating faces indefinitely.

The work's engagement with the death of the author is direct and structurally explicit. The faces generated are portraits without sitters: the painterly convention of the portrait, which from the Renaissance onwards has functioned as the visual inscription of individual identity and social

presence, is maintained as a formal structure while its referential content is emptied. Every face is a citation of the portrait tradition in the Jamesonian sense — a formal recombination of painted portraiture’s visual codes without the original sitter, and therefore without the original relationship between depiction and depicted that grounds the portrait as a genre. The endlessness of the generation, and the impossibility of identifying any individual face as primary or original, enacts the condition described by Barthes’ metaphor of the tissue of quotations: the faces are citations drawn from a vast corpus with no individual originating presence.

The work’s sale at Sotheby’s London in March 2019 — the first sale of an AI artwork at a major auction house — introduced a productive paradox. The object sold was the machine itself, a unique physical apparatus that generates infinite, non-repeating outputs. In selling the machine as a unique work, the market reasserted auratic singularity at the level of the generating apparatus even as the outputs themselves lack aura in Benjamin’s sense. This commercial transaction illustrates Groy’s (2008) argument that digital culture finds new locations for aura rather than abolishing it, and it suggests that the postmodern dissolution of the auratic original is never complete: the art market, and the cultural systems that depend on attributing singular value to unique objects, develop mechanisms to relocate aura even within conditions of infinite automated production.

7.4 Anna Ridler: Mosaic Virus (2018–2019)

Mosaic Virus occupies a distinctive position among the works examined here because it directly interrogates the process of dataset construction that other generative practitioners typically leave opaque. Ridler personally photographed 10,000 tulips, hand-labelling each image to construct the training dataset used to fine-tune a StyleGAN network. The resulting generative system produces continuously evolving tulip images whose appearance — the degree to which the flowers are open or closed, bright or pale — is controlled by the real-time price of bitcoin. The title refers simultaneously to the tulip mosaic virus, which causes the irregular streaking of tulip petals that made them particularly prized during the Dutch tulip mania of the seventeenth century, and to the visual artefacts produced by the GAN training process.

The work enacts postmodern intertextuality with an unusual degree of historical self-consciousness. The tulip functions as a richly overdetermined symbol, carrying within it the history of Dutch Golden Age floral painting, the first speculative financial bubble in modern history, and the contemporary speculation of the cryptocurrency market; the generative image brings these temporal layers into a single visual field, producing exactly the kind of knowing historical citation that characterises postmodern pastiche at its most analytically engaged. Unlike the frictionless stylistic recombination of commercial generative systems, Ridler’s citation is laboured, selected, and conceptually motivated — it retains the critical selectivity that distinguishes postmodern citation from mere stylistic reproduction.

The methodological significance of Ridler’s practice for the broader argument of this article lies in its demonstration that the intertextual fabric of the generative image can be made visible and accountable. By constructing and documenting her own training dataset, Ridler makes legible the labour and selectivity that commercial generative systems conceal behind the opacity of their training corpora. This transparency functions as a critique of both the standard practice of generative AI development and the postmodern tendency to celebrate intertextuality without attending to the conditions of its production. Mosaic Virus suggests that a critical generative practice is possible — one that employs the technical apparatus of generative production while retaining the reflexive self-awareness that postmodern theory identified as the condition of authentic critical practice.

8. Generative AI in Contemporary Visual Media

The deployment of generative AI across the field of contemporary visual media has been rapid and pervasive, extending from artistic practice through commercial design, advertising, film and television production, and the everyday visual culture of social media. This diffusion has had a complex and paradoxical relationship with the postmodern aesthetic logic that generative systems extend, simultaneously democratising and homogenising the production of visually complex imagery.

On one hand, generative tools have dramatically extended the capacity to produce sophisticated visual material, making techniques of image synthesis, stylistic recombination, and visual complexity accessible to a vastly larger community of producers than ever before. The democratisation of image production through generative tools fulfils, in one sense, a postmodern promise of the dispersal of cultural authority and the proliferation of voices. This extends the trajectory that Lev Manovich identified in the language of new media, in which the computer transforms the production and circulation of cultural objects.

On the other hand, the ready availability of generative tools has produced a new and acute version of the problem of aesthetic homogenisation. The characteristic visual signature of mainstream generative systems — the particular qualities of lighting, composition, texture, and finish that mark an image as the product of a popular generative model — has produced a recognisable and increasingly ubiquitous AI aesthetic that threatens to homogenise visual culture even as it democratises production. Where postmodern citation mobilised the diversity of historical styles to contest the universalism of modernist design, generative production tends towards a statistical mean, a most-probable image that reflects the central tendencies of its training distribution. The pluralism that postmodern aesthetics championed risks being supplanted by a new homogeneity grounded in the statistical structure of the training data and the optimisation objectives of the model.

Social media platforms, and image-sharing applications in particular, have become major sites for the dissemination and development of contemporary generative aesthetics. The platform's image-first, rapid-consumption format has shaped a distinctive visual culture characterised by high-contrast, bold compositions that perform visual complexity while remaining legible and impactful at small screen sizes. This screen-adapted generative aesthetic represents a significant evolution of the tradition, shaped by the constraints and affordances of digital distribution rather than fine art or print production contexts, and it constitutes a further mutation of the postmodern condition that design theory is only beginning to address.

9. Azerbaijan and the Post-Soviet Generative Turn

9.1 Visual Heritage, Training Data, and Cultural Representation

The dominant training datasets for contemporary image generation — including LAION-5B and similar large-scale web-sourced corpora — are overwhelmingly assembled from English-language web content and repositories reflecting the digitisation priorities of Western cultural institutions. This structural bias means that generative models trained on these datasets are systematically unable to generate culturally authentic representations of non-Western visual traditions. Azerbaijani visual culture is among the traditions particularly vulnerable to this underrepresentation, with consequences that bear directly on the claims of the postmodern pluralist thesis.

The ornamental and geometric traditions of Azerbaijani carpet design — comprising distinct regional styles including the Guba, Shirvan, Karabakh, Baku, and Ganja carpet traditions, each with its own vocabulary of motif, colour, and compositional logic — represent a visual language of extraordinary sophistication developed over many centuries. This language is

essentially absent from standard generative training datasets, with the consequence that generative systems cannot produce culturally authentic Azerbaijani ornamental imagery; stylistic prompts relating to these traditions yield outputs that conflate Azerbaijani with generically 'Middle Eastern' or 'Persian' visual codes, flattening a highly differentiated visual heritage into a statistical composite drawn from the dominant visual cultures represented in the training data. The tradition of Islamic calligraphy as practised in the South Caucasian context, and the distinct miniature painting traditions that flourished in the region, are similarly marginalised (Blair, 2006).

This situation illustrates the central paradox of the postmodern pluralist promise in its generative automation. The postmodern project of challenging the cultural imperialism implicit in universalist design ideologies — the assertion that modernism's universal visual language was in practice the visual language of a particular European tradition — is in principle extended by the pluralism of generative style. In practice, however, the pluralism of generative production reflects the pluralism of its training data, which in turn reflects the historically determined inequalities of cultural digitisation. Scholars including Crawford (2021) and Bender and colleagues (2021) have identified these structural biases as central to the politics of AI; in the visual domain, they constitute a form of representational imbalance in which the statistical averaging of training data marginalises non-dominant visual cultures. The generative system that appears to offer access to all styles is, in practice, a system that offers access to those styles most extensively represented in digitised Western archives.

9.2 Post-Soviet Aesthetic Transition and the Digital Visual Field

Azerbaijan's post-independence visual culture (from 1991) has been shaped by a complex layering of aesthetic influences that makes it, in certain respects, an unusually rich site for the analysis of postmodern aesthetic conditions. Soviet visual culture imposed a form of enforced aesthetic modernism: the doctrine of socialist realism produced a coherent and systematically enforced aesthetic programme that shaped the visual language of design, art, and public space across the Soviet period. This aesthetic programme constituted a kind of state-sponsored modernism, and its collapse in 1991 produced precisely the conditions of postmodern plurality — the simultaneous availability of multiple, incompatible aesthetic codes without the authority of a dominant ideology to organise them — that postmodern theory had described as the condition of late Western capitalism.

The post-Soviet transition brought rapid adoption of global commercial design aesthetics, mediated by the simultaneous transition from Cyrillic to Latin script (officially completed in the mid-1990s), which introduced a fundamental typographic and visual reconfiguration of the public sphere. In this context, postmodern aesthetics arrived in Azerbaijan not as a European luxury but as a practically useful framework for navigating the plurality of coexisting visual codes — Soviet and post-Soviet, vernacular and international, Cyrillic and Latin, Islamic and secular — that defined the post-independence visual environment. The Azerbaijani designer of the post-Soviet period was, in a structural sense, always already postmodern, inhabiting a visual culture defined by the simultaneous citation of multiple, incompatible historical registers without the authority of a unifying ideology to resolve their contradictions.

This historical context gives particular force to the postmodern dimensions of generative AI in the Azerbaijani setting. A generative system trained on Azerbaijani visual material would need to hold in its latent space not only the carpet patterns and miniature traditions of the pre-Soviet period but the socialist realist murals, Soviet typographic conventions, and propaganda aesthetics of the Soviet period, together with the global commercial design vocabulary of the post-independence era. The latent space of such a system would enact, at the level of statistical representation, the cultural layering that Azerbaijani visual culture has lived as historical experience. This convergence of the technical condition of the latent space and the historical

condition of post-Soviet cultural plurality suggests that generative AI, applied to the Azerbaijani visual archive, would produce not generic hyperreal imagery but a culturally specific articulation of the postmodern condition.

9.3 Emergent Generative Practice in the Azerbaijani Context

While the scholarly documentation of Azerbaijani generative art and design practice remains nascent — reflecting both the relative recency of generative tools and the underrepresentation of the South Caucasian region in international design scholarship — there are clear indications of an emergent engagement with generative tools among the younger generation of designers educated at institutions including Azerbaijan State University of Economics, the Azerbaijan State University of Culture and Arts, and internationally oriented institutions such as ADA University. This generation inherits the complex visual culture described in Section 9.2 and is simultaneously positioned within the global digital design culture through which generative tools have been disseminated.

The specific challenges of working with generative systems in the Azerbaijani context are both technical and cultural. At the technical level, the limitations of existing training data described in Section 9.1 mean that working productively with commercially available generative models requires either accepting the cultural biases embedded in those models or undertaking the substantial labour of constructing culturally specific training datasets. The precedent of Anna Ridler's *Mosaic Virus* (examined in Section 7.4) is instructive here: the deliberate curation of a culturally specific training dataset is not merely a technical expedient but a conceptually and artistically productive practice in its own right. A generative system trained on a carefully curated dataset of Azerbaijani carpet patterns, Soviet-era graphic design, and contemporary Azerbaijani visual material would constitute not only a design tool but an artistic and archival project, creating computational representations of visual traditions that are currently inadequately represented in global digital archives.

At the cultural level, the multilingual and multiscript character of Azerbaijani visual communication — designing for Azerbaijani (Latin), Russian (Cyrillic), and English-speaking audiences simultaneously, and navigating between Islamic ornamental traditions, Soviet aesthetic heritage, and global digital design culture — is precisely the kind of complex, culturally layered condition that postmodern aesthetic plurality is best equipped to address. Generative tools, applied reflectively and with cultural specificity, offer the Azerbaijani visual practitioner a means of engaging with this complexity as a resource rather than managing it as an obstacle. The development of a culturally grounded Azerbaijani generative practice would thus constitute a contribution not only to local design culture but to the global critical literature on generative AI, demonstrating that the postmodern aesthetic logic of generative systems can be articulated in culturally specific rather than universally homogenising terms.

The engagement of Azerbaijani designers and artists with generative tools participates in a global negotiation between the homogenising and pluralising tendencies of generative production that is being conducted simultaneously in many non-Western cultural contexts. The outcomes of this negotiation — whether generative AI proves to be a further mechanism of cultural homogenisation or a genuinely pluralising tool in the hands of practitioners who bring culturally specific visual knowledge to its application — will depend significantly on whether the technical infrastructure of generative AI, including training data, model development priorities, and the economics of access, is reformed to support the representation of non-dominant visual cultures. The Azerbaijani context, with its rich visual heritage and its position at the intersection of multiple historical and cultural currents, represents a significant and underexplored site for this negotiation.

10. Implications for Practice, Pedagogy, and Cultural Theory

The analysis of generative AI as an extension of postmodern aesthetics, qualified by the critical perspectives examined in Section 6 and the cultural specificity examined in Section 9, carries significant implications for visual practice, design education, and cultural theory. For practitioners, the central challenge is to engage with generative tools not as neutral instruments for the efficient production of images but as an apparatus that embeds specific aesthetic and conceptual logics — along with specific structural biases concerning the representation of cultural traditions — and to develop critical and reflexive modes of practice that mobilise the generative apparatus towards meaningful ends rather than defaulting to its statistical tendencies.

For design and art educators, the analysis suggests that the integration of generative tools into curricula must be accompanied by critical engagement with their aesthetic, conceptual, and political dimensions. Students who understand the lineage connecting generative production to the postmodern aesthetics of pastiche, simulation, and the dispersal of authorship — but who also understand the critical perspectives that contest this lineage, and the cultural and political conditions that shape what generative systems can and cannot represent — are better positioned to deploy generative tools as reflective practitioners than students who encounter these tools merely as efficient means of image production. The pedagogical framework developed from this analysis suggests a generative literacy that encompasses theoretical foundations, critical perspectives, technical understanding, and cultural specificity in equal measure.

For cultural theory, generative AI poses the question of whether the conceptual vocabulary of postmodernism remains adequate to the conditions it has helped to produce, or whether the automation and intensification of postmodern aesthetic logics by generative systems calls for new theoretical resources. The tensions that generative production introduces — concerning the appropriation of creative labour, the political economy of training data, the environmental costs of computation, the homogenisation of visual culture, and the underrepresentation of non-Western visual traditions — exceed the frame of the aesthetic analysis with which postmodern theory was primarily concerned, and demand an engagement with the material, economic, and political conditions of generative production that postmodern aesthetics often deferred. The critical literature on artificial intelligence developed by scholars including Crawford (2021) and Bridle (2018) represents an essential supplement to postmodern aesthetic theory, situating the aesthetic phenomena analysed in this article within the material and political conditions of their production.

11. Conclusion

Generative artificial intelligence represents not a rupture with the history of visual culture but the automation and intensification of the aesthetic logic of postmodernism. This article has argued that the core strategies and conditions identified by postmodern aesthetic theory — pastiche, simulation, intertextuality, deconstruction, the dissolution of the original, and the dispersal of authorship — are materialised, operationalised, and intensified by generative systems built on adversarial and diffusion architectures. An analytical framework mapping these postmodern concepts to their generative analogues was presented in Table 1 and applied in both the theoretical and the empirical dimensions of the analysis.

The case study analysis of four paradigmatic works — Anadol's *Machine Hallucinations* and *Unsupervised*, Klingemann's *Memories of Passersby I*, and Ridler's *Mosaic Virus* — demonstrated the range of ways in which generative art practice engages with the postmodern aesthetic thesis. Anadol's work enacts simulation and intertextuality at institutional scale; Klingemann's work literalises the death of the author and produces a paradoxical reassertion of auratic singularity through commercial transaction; Ridler's work demonstrates that critical generative practice is

possible — one that employs the technical apparatus of generative production while retaining the reflexive self-awareness that distinguishes postmodern practice from mere stylistic reproduction.

The critical perspectives examined in Section 6 — Manovich’s data realism framework, the legal and philosophical arguments for the persistence of authorship, and Cramer’s post-digital thesis — indicate the limits of the postmodern analogy and the necessity of supplementing it with critical resources adequate to the specific conditions of generative production. The analysis of the Azerbaijani context in Section 9 extended these critical resources to the domain of cultural politics, demonstrating that the structural biases of generative training data reproduce the inequalities of cultural digitisation, and that the realisation of the postmodern pluralist promise in generative production requires both technical reform and the development of culturally specific generative practices.

The continuing evolution of generative AI in visual media, and its distinctive development in emerging and non-Western cultural contexts including the Azerbaijani design and art scene, represent productive areas for future research. A fuller understanding of how generative tools are adapted, contested, and transformed across diverse cultural contexts, and of the relationship between the recombinatory aesthetics they automate and the material conditions of their production, promises to enrich both cultural theory and the critical resources available to contemporary practitioners navigating the generative transformation of visual culture.

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Artificial Intelligence-Supported Feedback for Teacher Professional Development: Opportunities and Challenges

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Abstract

Few levers in teacher professional development are as well supported by evidence, or as hard to supply at scale, as timely individual feedback on classroom practice. Artificial intelligence is now being offered as a way out of that bind. This article reviews the recent international literature on AI-supported feedback for teachers, published between roughly 2017 and 2026, and reads the resulting opportunities and risks as one connected argument before turning to the Republic of Kazakhstan and the work of the JSC National Center for Professional Development “Örleu.” Tools built on natural language processing and large language models, among them M-Powering Teachers and TeachFX, can return cheap, consistent, descriptive feedback on how teachers talk; in at least one large randomised trial they shifted both teaching practice and student outcomes. The same literature explains why enthusiasm should be tempered. The reliability of automated judgements is still unsettled. Models carry bias, recordings raise real questions about privacy and surveillance, teachers may be deskilled or their relationships with students worn thin, and the evidence remains young, short-term, and heavy on self-report. For Kazakhstan one further constraint is decisive: Kazakh is a low-resource language that current speech and language models handle poorly. Reading the UNESCO AI Competency Framework for Teachers (2024) against Kazakhstan’s 2024–2029 policy settlement, the article makes the case for a staged, human-centred model in which AI-supported feedback widens the reach of mentoring instead of standing in for it.

Keywords: *artificial intelligence; feedback; teacher professional development; natural language processing; large language models; classroom discourse; Kazakhstan; Örleu; AI ethics*

Introduction

Few findings about teacher learning are as secure as this one: teachers improve when someone gives them specific, well-timed feedback on what they actually do in class. Reviews of effective professional development keep describing the same profile. The work that changes practice is sustained, embedded in the job, and collaborative, built around modelling, coaching, and structured reflection (Darling-Hammond et al., 2017); Borko (2004) reads the same process cognitively, as repeated cycles of enactment and reflection. The obstacle is practical rather than conceptual. The most useful feedback of all, an expert watching a lesson and responding to its particulars, draws on the scarcest resource any system has: the time of skilled observers (Demszky et al., 2024).

That shortage bites hardest where a single authority answers for a teaching workforce scattered across a wide territory. Into the gap between what individual feedback can do and what staffing can actually reach steps artificial intelligence. Advances in natural language processing, and large language models now able to cope with real classroom talk, make something new feasible: record a lesson, analyse its discourse, and return descriptive comment on particular

teaching moves, at a cost that no longer climbs with every extra teacher served (Demszky et al., 2024; Vitale et al., 2025).

The same capabilities unsettle. Once an algorithm starts to interpret teaching, hard questions follow. Can its judgements be trusted? Whose norms does its training quietly encode? What happens to the recordings, and are teachers being helped, or simply deskilled and watched (Alghamdi & Alghizzi, 2025; Doyle et al., 2025)? UNESCO’s competency framework for teachers takes a clear position on this, making a human-centred stance its starting premise: teachers stay in charge of the tools and answerable for how they are used (Miao & Cukurova, 2024).

For Kazakhstan the question is not abstract. In 2025 the state stood up a Ministry of Artificial Intelligence and Digital Development and adopted its first national standards for AI in education, covering 2024 to 2029 (Astana Times, 2025). The body that carries most in-service teacher development, the JSC National Center for Professional Development “Örleu,” already works at a scale that makes it one of Central Asia’s more consequential prospective adopters, having put very large numbers of teachers through AI-related courses (UNESCO-ICHEI, 2025). This article pulls the international evidence into one synthesis, treats opportunities and risks as connected rather than separate, and asks what the whole picture means for Kazakhstan and for “Örleu.” Three questions organise what follows:

1. What does “AI-supported feedback” mean in teacher development, and what can honestly be claimed about its effects on current evidence?
2. Which opportunities and risks does it carry, and how are the two bound together?
3. How should Kazakhstan’s national system, and “Örleu” in particular, take it up responsibly?

Figure 1 sketches the policy arc behind the discussion, from the early intergovernmental statements through to Kazakhstan’s own reforms.

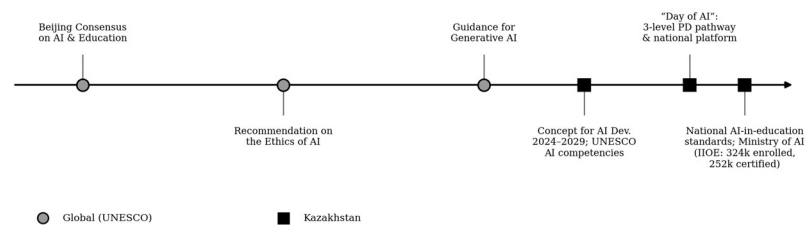


Figure 1. *Milestones in the governance of AI in education, 2019–2025: intergovernmental (UNESCO) and national (Kazakhstan).*

Note. Circles mark UNESCO instruments; squares mark Kazakhstani measures. Compiled from Astana Times (2025), Prime Minister of the Republic of Kazakhstan (2025), UNESCO-ICHEI (2025), and Miao and Cukurova (2024).

Background and conceptual framing

Much of the professional-development literature reads as one long argument against the one-off workshop. Isolated events rarely change practice. Programmes that are sustained, embedded in the job, and built on repeated observation and response usually do (Darling-Hammond et al., 2017). Coaching works because it gives a teacher what a workshop cannot: a reading of their own practice, returned soon enough, and concretely enough, to shape the next lesson. Borko (2004) puts the mechanism in cognitive terms. Teachers learn by making sense of how students respond and then rebuilding their practice around that understanding. Good feedback, on this account, is less a verdict than a mirror; it shows teachers what usually slips past them.

It is easy to confuse the term with machines marking students’ work. The feedback meant here points the other way, at the teacher, and concerns the teacher’s own practice. Inside that

scope the field splits into two technical families. The first analyses classroom discourse. It transcribes a lesson, computes features of the talk such as the ratio of teacher to student talk, the uptake of student ideas, the kinds of questions asked and the chances students get to contribute, and reports them plainly (Demszky et al., 2024; Vitale et al., 2025). The second is generative. It uses large language models to write narrative feedback, critique a lesson plan, or stand in as a simulated student or coach (Kelly et al., 2024; Hicke et al., 2023). The difference matters. Measuring a well-defined feature of talk is a narrower and more checkable task than producing open-ended advice, and the two families differ accordingly in how far their output can be trusted.

Three traditions help locate the topic. Technology-acceptance models, chiefly the Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology, explain uptake through perceived usefulness, ease of use, social influence, and the conditions that enable use; they predict that teachers adopt a tool only when it plainly helps at a cost they find acceptable. Acceptance, though, says nothing about whether a tool deserves to be used. That is the province of a second tradition, built around fairness, accountability, transparency, and ethics. Alghamdi and Alghizzi (2025) are instructive here precisely because they refuse to keep the two apart, treating educators' willingness to adopt automated feedback as conditional on whether it can be defended ethically. A third lens, human-centred AI, holds the others together. Its claim is that such systems should augment human judgement rather than replace it, and UNESCO's framework turns that claim into concrete expectations for teachers (Miao & Cukurova, 2024). Read together, the three suggest that success turns less on a model's accuracy than on whether tools are adopted, governed, and used in ways that leave teachers in authority.

What follows is a structured narrative review, not a meta-analysis. The field is too young for anything else. The evidence is small, recent, and mixed in method, ranging from randomised trials and interview studies to technical evaluations and policy documents, and forcing it into a single pooled effect size would manufacture a precision it does not have. The review therefore works across the evidence by theme, asking which claims keep recurring and where they rest on the firmest ground. The sources include peer-reviewed journals in education and educational technology, the proceedings of Learning @ Scale and the conference on Artificial Intelligence in Education, a number of preprints, and, for the policy backdrop, intergovernmental frameworks together with Kazakhstani government and institutional material, spanning 2017 to early 2026. Two limits should be stated plainly. The base of rigorous studies is thin, and it is almost entirely in English, a skew that begins to matter as soon as the discussion reaches Kazakh-medium classrooms.

The international evidence

The most convincing evidence sits with tools that measure features of talk and report them without passing judgement. The clearest signal comes from M-Powering Teachers, which tells instructors how often they take up what students say. In a randomised controlled trial of more than eleven hundred instructors in a large online course, it lifted that uptake by about an eighth, and the gain came with higher student satisfaction and better course completion (Demszky et al., 2024). An earlier study found similar benefits in one-to-one teaching (Demszky & Liu, 2023). Two design choices recur, and they seem to matter as much as the technology behind them. The feedback is descriptive rather than evaluative, closer to a fitness tracker than to an inspector, and it stays narrowly fixed on a single feature of practice. Later work pushes the same logic further, fine-tuning GPT-4o to spot the openings teachers leave for students to respond (Vitale et al., 2025) and looking at how teachers take such metrics in, where simply seeing one's own discourse data can be enough to start reflection (Kelly et al., 2024).

The generative family promises feedback in prose, and the chance to rehearse against a simulated student or coach. Its difficulty is the mirror image of that promise. Measuring uptake is a bounded, checkable task; producing open-ended advice rewards fluency whether or not the

advice is sound. One evaluation of large language models writing teacher responses found that even the best model produced answers more fluent than they were pedagogically sound, and its authors warn that coherence is no proof of instructional usefulness (Hicke et al., 2023). That gap, between sounding right and being right, is the central liability. As a prompt for a teacher's own thinking, these tools can help. As an unsupervised source of authoritative judgement, they are not yet to be relied on.

Taken together, these studies support one narrow conclusion and caution against a broader one. They show that automated feedback is feasible and cheap to run at scale, and that in careful, narrowly targeted forms it can move specific, measurable practices, with at least one randomised trial picking up an effect on students themselves (Demszky et al., 2024). They do not show much of what a system would want to know before leaning on it heavily: whether the gains last, whether they carry beyond English-language and largely online settings, what happens to the harder things to measure such as rapport, or whether generative feedback is valid at all. Those are the usual blind spots of a young field that leans on short windows and self-report (Alghamdi & Alghizzi, 2025). One pattern holds across the work. Narrowly scoped, non-evaluative tools that have been tested in trials stand on firmer ground than ungoverned or evaluative uses.

Opportunities

The case starts with arithmetic. Observation that actually changes practice has always been rationed by the supply of skilled observers. Automated analysis pushes the cost of giving one more teacher an account of their lesson close to zero, so the attention once kept for a few can reach everyone (Demszky et al., 2024). A tool also pays attention consistently, and on demand rather than on a coach's calendar; feedback that comes back within hours reaches a teacher while the lesson is still fresh in mind.

The most distinctive thing these tools offer is visibility. Teachers routinely misjudge how much they talk, how long they wait after a question, or who gets the chance to speak. A measure drawn from a transcript makes those habits visible, and meeting one's own data can start a teacher reflecting without anyone telling them what the numbers ought to mean (Kelly et al., 2024). The benefit lands most heavily where ordinary support reaches least, with teachers in remote schools who are far from any expert coach. And because the counting is handled for them, human mentors are left free to do the interpreting, the encouraging, and the caring.

At the level of the system, patterns drawn together and stripped of names can show where a whole cohort struggles, which lets a body such as Örleu point its programmes where they are actually needed. The promise is genuine. Yet the very ability to gather teaching data for well-meant planning is also, under different governance, the ability to monitor. The next section takes up that tension.

Challenges

The reasons for caution start with a basic question: do the measurements mean what they appear to? Every metric stands in for something else. Talk-ratio stands in for participation, a count of questions for the quality of questioning. Some of these proxies track something real; others flatten a complex act into a tidy but misleading number. The problem is sharpest with generative feedback, where fluency and accuracy pull apart (Hicke et al., 2023). Even a sound measure only catches what it was designed to catch, and intent, rapport, and the history of a particular class stay largely out of its reach.

Whatever a system learns, it learns from data that carry the marks of where they came from. A tool trained mostly on English, and on one set of classroom conventions, can read anything different as a fault, penalising an accent, a switch between languages, or a culturally distinct way of taking turns. That worry is acute in a room where several languages are in play. Producing the feedback also means recording the classroom, which captures teachers and children alike and raises plain questions of consent and data protection. The same dataset gathered to help a teacher

reflect is also a dataset for watching that teacher work, and the slide from formative comment to quiet appraisal needs nothing more than a change of purpose (Doyle et al., 2025).

There is a cost inside the profession too. Teachers say they value the time these tools save, and in the same breath worry that their own judgement may dull and that relationships may thin when feedback arrives from software instead of a trusted colleague (Doyle et al., 2025). A skill left unused fades. Using this kind of feedback well is itself a skill, knowing what a metric means and when to set it aside, and where that skill is missing the danger is not that teachers reject the tool but that they defer to it too readily, trusting it for no better reason than that it is a machine.

Underneath all of it lies how little is firmly settled. The rigorous evidence is thin and recent, weighted toward short windows and self-report, and the one available synthesis reads educators' acceptance as conditional rather than eager, casting these systems as a supplement to human judgement rather than a replacement for it (Alghamdi & Alghizzi, 2025). Looked at this way, opportunities and challenges are not really two opposing columns. They are one list read twice, since the feature that delivers a benefit is usually the same feature that creates the matching risk, as Table 1 sets out.

Table 1. *Opportunities and their corresponding risks, paired by the underlying property*

Dimension	Opportunity	Corresponding risk
Scale & cost	Individualised feedback for the whole workforce at marginal cost	Adoption may outrun the evidence; experimentation at scale demands rigorous evaluation
Consistency	The same standards applied to every lesson; less observer subjectivity	Encoded norms may embed bias against non-standard speech and styles
Timeliness	Feedback within hours, while the lesson is still fresh	Speed can crowd out the slower, deeper sense-making of human coaching
Personalisation	Surfaces patterns teachers cannot self-perceive; supports reflection	Validity is partial; metrics miss intent, rapport, and context
Equity of access	Extends support to rural and remote teachers	Infrastructure gaps and the digital divide can widen disparities
Human relationship	Frees coaches for interpretation, motivation, and care	Over-reliance risks deskilling and relational erosion
Data & insight	Aggregated patterns inform PD and curriculum design	Privacy, consent, and the slide from formative use to surveillance

Note. In each row a single capability of the technology produces both the benefit and the risk beside it; which one prevails is settled by governance, not by the model.

The Kazakhstan context and the role of “Örleu”

Kazakhstan runs one of the region's more centralised systems for in-service training. National law requires teachers to take professional development at regular intervals, ordinarily at least once every five years, through programmes the state organises and pays for (Ministry of Education of the Republic of Kazakhstan, 2024). Delivery runs mainly through the regional branches of “Örleu,” alongside the Center of Excellence of Nazarbayev Intellectual Schools and the Y. Altynsarin National Academy of Education, with Örleu acting as the national hub.

Two recent moves leave the system both well placed and exposed. In 2025 the country created a Ministry of Artificial Intelligence and Digital Development and approved its first national standards for AI in education, running to 2029, which put ethics, data protection, and academic integrity up front and folded AI into Digital Literacy and Informatics (Astana Times, 2025). It also set out a three-level development pathway and a national platform able to certify teachers at scale (Prime Minister of the Republic of Kazakhstan, 2025). Those three ascending levels line up almost exactly with the progression levels in the UNESCO framework, which gives any scheme of feedback competencies a ready scaffold (Miao & Cukurova, 2024).

Capacity is starting to catch up with ambition. Late in 2025 the National Investment Corporation of the National Bank of Kazakhstan took a direct stake in Anthropic, the company behind the Claude models, joining its Series F round with a reported US\$25 million and making the state, for the first time, a shareholder in a frontier AI firm (Qazinform, 2026). On another front the country has drawn on Chinese expertise: specialist reporting describes a national model built with the laboratories 01.AI and DeepSeek (China Chatbot, 2026), while a home-grown system, KazLLM, trained at Nazarbayev University in Kazakh, Russian, English, and Turkish, carries a parallel bid for sovereign capability (The Diplomat, 2025). The mix is itself revealing. Access to frontier and regional models is precisely what localising feedback tools for Kazakh will take, and the same reliance on outside systems is the exposure a national model is meant to cover.

Örleu, it should be said, has already run AI-related training at a national scale. By adapting international online courses for local use, it enrolled 324,000 teachers and saw 252,000 finish with state-recognised certification, roughly three in four of those who started (UNESCO-ICHEI, 2025), as Figure 2 shows. Whatever the obstacles set out below, this is a system that has acted at scale rather than one still thinking about it.

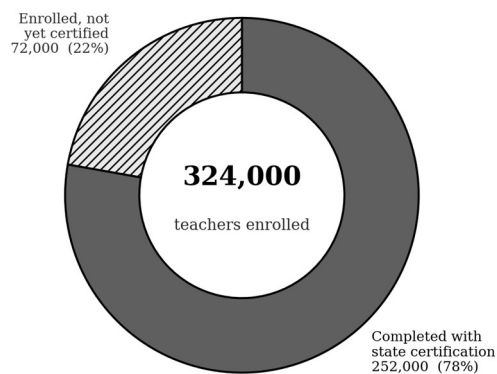


Figure 2. Participation in Örleu’s AI-focused professional development on the international online platform.

Note. Of 324,000 teachers enrolled, 252,000 completed with state-recognised certification. Figures from UNESCO-ICHEI (2025).

The general opportunities apply here with extra force. A centralised system, a legal duty to keep developing, one national hub, and a platform that already works add up to near-ideal conditions for handing out feedback consistently and fairly, including to the rural teachers for whom expert observation has long been scarce. The three-level pathway gives the work a staged structure, and Örleu’s proven reach lowers the odds that a sound design falls apart in the rollout. In time, insight gathered across the cohort and stripped of names could steer modules toward the weaknesses that genuinely keep recurring.

The most distinctive obstacle is language. The validated tools, and the speech and language models underneath them, are built overwhelmingly for English. Kazakh is another matter: a low-resource, agglutinative, mixed-script language that general multilingual models handle poorly and that even strong speech recognisers transcribe less accurately unless real work is put in (Li et al., 2024). Feedback depends first on an accurate transcript, so an error there travels all the way

downstream, and a system that cannot reliably transcribe a Kazakh-medium lesson cannot give valid feedback on it. Figure 3 shows where the constraint bites. The number of Russian-medium and bilingual classrooms tangles the chain further still.

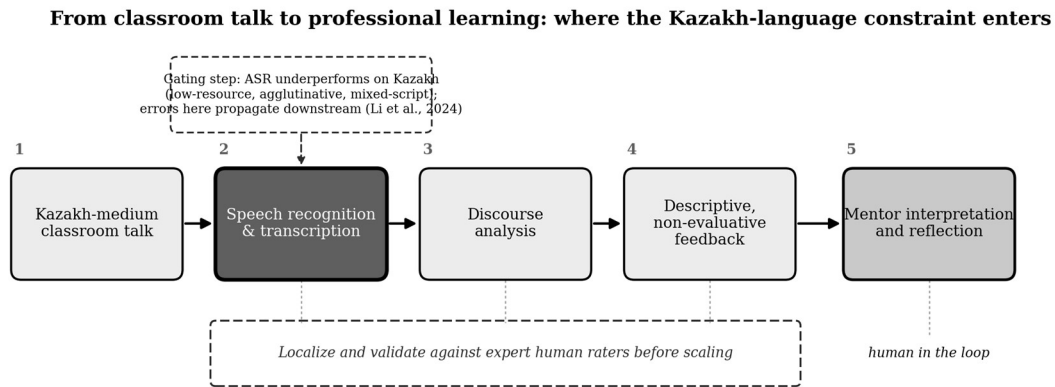


Figure 3. The AI-supported feedback pipeline, showing where the status of Kazakh as a low-resource language constrains validity.

Note. An error at transcription travels through every later step, so localisation and validation must come before national scaling. Drawn on Li et al. (2024).

From there the other difficulties follow in sharper form. A model that has not been adapted to local speech and curriculum imports the bias problem wholesale. The gap between rural and urban connectivity could turn an opportunity for equity into its opposite. And running awareness-level courses, which Örléu has shown it can do, is far easier than building teachers’ capacity to question AI feedback and act on it sensibly. Centralisation, finally, concentrates one temptation in particular, the reuse of feedback data for appraisal, and only deliberate design holds it off. The new standards put ethics and data protection up front (Astana Times, 2025); whether they are honoured, by keeping feedback formative, consented to, and owned by teachers, will do more for trust and uptake than any feature of the tools themselves.

Pulling the evidence and the context together, the model proposed here keeps AI-supported feedback in a supporting role to Örléu’s mentoring rather than in place of it. It advances in stages tied to the UNESCO levels, and it sits inside the governance layer the standards already demand. Figure 4 gives the logic of it; Table 2 sets out an indicative sequence.

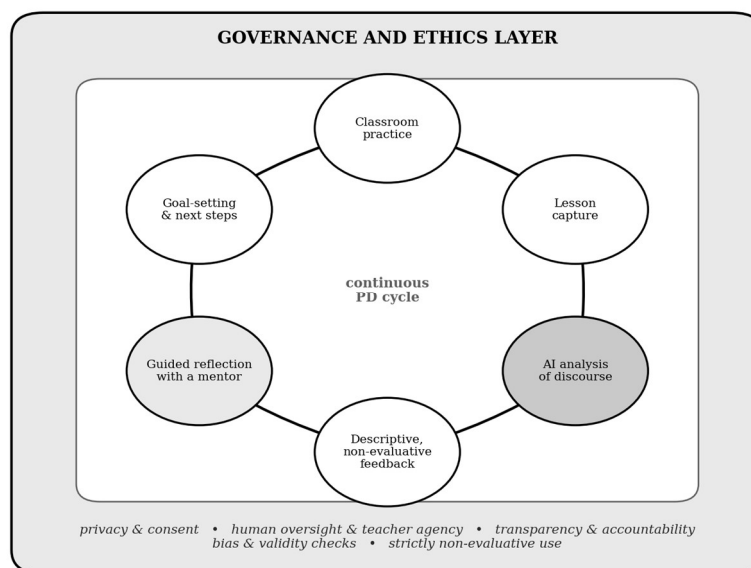


Figure 4. A human-in-the-loop model of AI-supported feedback within a continuous professional-development cycle.

Note. AI analysis informs the cycle but never closes it; the surrounding governance layer of consent, oversight, transparency, bias and validity checks, and strictly non-evaluative use conditions every stage.

Table 2. *An indicative phased pathway for “Örleu,” mapped to UNESCO (2024) progression levels*

Phase	UNESCO level	Focus	Key safeguards & enablers
1. Foundations	Acquire	Build AI literacy across the workforce; make tools formative and teacher-owned; pilot voluntarily	Informed consent; formative-only policy; baseline ethics and data-protection rules
2. Localisation	Acquire → Deepen	Invest in Kazakh- and Russian-language transcription and discourse models; validate against expert human raters	Diverse local data; bias auditing; independent validation before scale-up
3. Integration	Deepen	Embed AI feedback in Örleu mentor coaching cycles; AI measures, humans interpret and support	Mentor capacity-building; human-in-the-loop; teacher right to contest outputs
4. Scale & learn	Create	Extend nationally with continuous evaluation; use aggregated insight to redesign PD	Longitudinal evaluation; transparency reporting; firewall between feedback and appraisal

Note. The phases accumulate rather than replace one another; localisation (Phase 2) is a precondition for valid feedback in Kazakh-medium classrooms. Progression levels from Miao and Cukurova (2024).

Discussion

The conclusion belongs to neither the optimist nor the sceptic. AI-supported feedback answers a real and stubborn problem, the plain impossibility of giving every teacher timely, individual observation by human means alone, and in its best-designed forms it works, shifting specific practices and, in one large trial, student outcomes (Demszky et al., 2024). The trouble is that benefit and risk run along the very same features. The scale that makes feedback affordable also makes its mistakes count for more. The data that feeds reflection is the data that enables surveillance. The convenience that saves time can quietly erode judgement (Alghamdi & Alghizzi, 2025; Doyle et al., 2025). What settles which way it goes is not how clever the model is but the human and institutional arrangement around it: whether the feedback stays formative, whether teachers can question it, whether bias is audited and privacy protected, and whether a person, in the end, remains accountable. That is the human-centred stance UNESCO sets out (Miao & Cukurova, 2024).

For Kazakhstan this sharpens the task rather than settling it. A centralised system, a legal mandate, a national platform, and Örleu’s proven delivery make a sturdier base for responsible adoption than many more fragmented systems can offer. The same centralisation, though, raises the stakes on governance, and the language constraint fixes the order of operations: localise and validate first, scale afterwards, because feedback that cannot be grounded in Kazakh-medium talk is not yet feedback at all (Li et al., 2024). The pace should be set by validity and trust, not by how fast a contract can be signed. One principle holds the whole argument together, augmentation rather than replacement. The machine does the measuring; the human keeps the interpreting,

the motivating, and the caring, which for an institution built around teachers' growth is a strength rather than a limit.

Limitations

A few limitations bound these conclusions. This is a structured narrative review rather than a meta-analysis, so it reads across uneven evidence without pooled estimates, and although the selection of sources was systematic it was not exhaustive. The evidence itself is young and patchy, tilted toward short-term and self-reported outcomes (Alghamdi & Alghizzi, 2025), and the most rigorous trials were run in English and often online, which limits how far they carry to Kazakh- and Russian-medium classrooms. Both the field and Kazakhstan's reforms are moving fast, so particular tools and particular rules will already have shifted. And the model proposed for Örleu is a reasoned design, not a tested programme. It is a hypothesis to be piloted and evaluated, which is only consistent with the argument made here.

Conclusion

AI-supported feedback offers a credible answer to one of the oldest constraints in teacher development, the shortage of timely, individual observation. The evidence shows that carefully designed, narrowly scoped tools can shift specific practices, and in the best-evidenced case student outcomes too, at a fraction of the usual cost (Demszky et al., 2024). The same evidence shows those gains to be contingent on governance, on training, and on a steady refusal to let feedback drift from formative into evaluative (Alghamdi & Alghizzi, 2025; Doyle et al., 2025; Miao & Cukurova, 2024). For Kazakhstan and for Örleu the opportunity is real and the foundation is strong, but the path comes with conditions. Adoption should be staged and human-centred. It should treat the localisation and validation of Kazakh- and Russian-language tools as prerequisites, not afterthoughts. And it should hold the line between formative support and evaluative surveillance. Taken that way, as a means of widening mentoring and paced by validity and trust, AI-supported feedback can help Örleu bring strong support to every teacher without giving up the relationships that make the support worth having. The choice was never between technology and teachers. The task is to build the arrangement in which each makes the other better.

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Влияние образовательной платформы Blockland.kz на развитие когнитивных функций студентов

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Аннотация. В статье представлены результаты экспериментального исследования, направленного на определение влияния образовательной платформы Blockland.kz на развитие когнитивных функций студентов. Актуальность исследования обусловлена активным внедрением цифровых образовательных платформ в учебный процесс, а также требованиями нормативных документов Республики Казахстан, ориентированных на развитие функциональной грамотности, цифровой грамотности, алгоритмического и вычислительного мышления обучающихся. Объектом исследования выступает процесс применения платформы Blockland.kz в учебной деятельности студентов, предметом — динамика когнитивных параметров обучающихся при использовании блочного программирования, его аналогов на Python и Java, тренажеров и набора программных задач.

В исследовании приняли участие 157 студентов 2–3 курсов в возрасте 16–20 лет из трех образовательных организаций: Жетысуского университета имени И. Жансугурова, Казахского национального женского педагогического университета и Талдыкорганского высшего политехнического колледжа. Экспериментальная группа составила 79 человек, контрольная группа — 78 человек. Исследование проводилось в течение двух семестров. Для диагностики когнитивных функций использовались таблицы Шульте, тест на память, адаптированный GALT-тест, задания на алгоритмическое и критическое мышление, анализ учебной успеваемости, анкетирование и полуструктурированное интервью участников образовательного курса.

Результаты исследования показали положительную динамику внимания, памяти, логического, алгоритмического и критического мышления, скорости выполнения программных задач, учебной мотивации и успеваемости в экспериментальной группе. На основе анализа количественных данных, результатов опроса и интервью сформулированы рекомендации по дальнейшему совершенствованию платформы Blockland.kz. Сделан вывод о педагогической эффективности платформы как цифровой среды, способствующей развитию когнитивных функций студентов при условии ее систематического и методически обоснованного применения.

Ключевые слова: Blockland.kz, цифровая образовательная платформа, блочное программирование, когнитивные функции, логическое мышление, алгоритмическое мышление, критическое мышление, вычислительное мышление.

Введение

Современная система образования Республики Казахстан развивается в условиях цифровой трансформации, обновления содержания обучения и повышения требований к функциональной грамотности обучающихся. В государственных общеобразовательных

стандартах образования закреплены требования к уровню подготовки обучающихся, ожидаемым результатам обучения, формированию ключевых компетенций и готовности применять знания в учебных, практических и жизненных ситуациях. Это усиливает значимость образовательных технологий, направленных не только на усвоение учебного материала, но и на развитие познавательной активности, логического анализа, алгоритмизации, самостоятельного решения задач и критической оценки результата.

Особую роль в данном процессе играют цифровые образовательные платформы, интерактивные тренажеры, онлайн-курсы и программные среды. Они становятся не только средством передачи учебной информации, но и инструментом изменения характера учебной деятельности. Цифровая среда позволяет организовать обучение в интерактивной форме, обеспечить индивидуальный темп освоения материала, повысить самостоятельность обучающихся и усилить практическую направленность образовательного процесса.

Нормативные документы Республики Казахстан также подтверждают актуальность исследования. Государственные общеобязательные стандарты образования определяют требования к содержанию образования, уровню подготовки обучающихся и результатам обучения. Типовые учебные программы по предметам «Цифровая грамотность» и «Информатика» ориентированы на формирование у обучающихся цифровых навыков, алгоритмического мышления, умения работать с информацией, строить алгоритмы и применять программные средства для решения учебных задач. В системе технического и профессионального образования программа общеобразовательной дисциплины «Информатика» также направлена на развитие логического, алгоритмического и вычислительного мышления обучающихся, необходимых для решения профессионально ориентированных задач.

Вместе с тем активное внедрение цифровых платформ требует научно обоснованной оценки их эффективности. В педагогической практике нередко встречается ситуация, когда цифровой ресурс декларируется как средство развития мышления, внимания, памяти или мотивации, однако его реальное влияние на когнитивные функции обучающихся не подтверждается экспериментальными данными. В связи с этим особую значимость приобретает проведение исследований, в которых цифровая образовательная платформа рассматривается не только как технический инструмент, но и как педагогическое средство, способное оказывать измеряемое влияние на познавательное развитие студентов.

Одним из перспективных направлений цифрового обучения является использование программирования как инструмента развития когнитивных функций. Программирование требует от обучающегося анализа условия задачи, выделения исходных данных, построения последовательности действий, проверки результата, исправления ошибок и поиска рационального способа решения. Эти действия непосредственно связаны с развитием внимания, памяти, логического мышления, алгоритмического мышления, критического мышления и скорости обработки информации.

Особое значение имеет блочное программирование, поскольку оно позволяет снизить начальный барьер вхождения в программирование. Визуальные блоки помогают обучающимся сосредоточиться на логике построения алгоритма, не перегружая их синтаксическими особенностями конкретного языка программирования. При этом сопоставление блочных конструкций с текстовым кодом на Python и Java обеспечивает постепенный переход от визуального алгоритма к профессионально ориентированному программному коду.

Образовательная платформа Blockland.kz представляет собой цифровую среду, включающую блочное программирование, аналоги программных конструкций на Python и Java, тренажеры и набор задач. Ее использование позволяет организовать учебную

деятельность на основе практического решения задач, анализа ошибок, самостоятельного построения алгоритмов и постепенного усложнения программных действий. В данном исследовании платформа Blockland.kz рассматривается как средство развития когнитивных функций студентов.

Проблема исследования заключается в противоречии между широким распространением цифровых образовательных платформ и недостаточной доказательной базой, подтверждающей их влияние на когнитивное развитие обучающихся. Данное противоречие определяет необходимость экспериментальной проверки того, как систематическое использование платформы Blockland.kz влияет на внимание, память, логическое, алгоритмическое и критическое мышление студентов.

Цель исследования — экспериментально определить влияние образовательной платформы Blockland.kz на развитие когнитивных функций студентов и сопоставить полученные результаты с исходными теоретическими ожиданиями.

Для достижения поставленной цели были определены следующие задачи:

1. Проанализировать теоретические и нормативные основания развития когнитивных функций обучающихся средствами программирования и цифровых образовательных технологий.
2. Описать функциональные возможности платформы Blockland.kz как инструмента организации учебной деятельности студентов.
3. Разработать и внедрить образовательный курс, основанный на конструкторах блочного программирования.
4. Реализовать экспериментальный дизайн исследования с участием контрольной и экспериментальной групп.
5. Провести диагностику внимания, памяти, логического, алгоритмического и критического мышления студентов до и после эксперимента.
6. Выявить динамику учебной успеваемости и мотивации обучающихся.
7. Сопоставить полученные результаты с предварительными ожиданиями исследования.
8. Проанализировать результаты опроса и интервью студентов и преподавателей.
9. Сформулировать выводы и рекомендации по дальнейшему совершенствованию платформы Blockland.kz.

Гипотеза исследования состоит в предположении о том, что систематическое применение платформы Blockland.kz в течение двух семестров способствует положительной динамике когнитивных функций студентов, поскольку работа с блочными алгоритмами, программным кодом на Python и Java, тренажерами и задачами активизирует внимание, память, логическое, алгоритмическое и критическое мышление.

Теоретические и нормативные основания исследования

Теоретическую основу исследования составляют положения когнитивной психологии, конструктивистского и конструкционистского подходов, а также современные исследования в области цифровизации образования, программирования и развития когнитивных функций обучающихся.

В трудах Ж. Пиаже и Б. Инельдер логическое мышление рассматривается как результат развития интеллектуальных операций, связанных с классификацией, сериацией, сохранением, пропорциональными, вероятностными и комбинаторными рассуждениями. Данные положения имеют значение для настоящего исследования, поскольку программирование требует от обучающегося выполнения последовательных мыслительных действий: анализа условия, выделения исходных данных, построения алгоритма, проверки результата и исправления ошибок.

С. Пейперт рассматривал программирование как средство интеллектуального развития обучающихся. В рамках конструкционистского подхода студент не только воспринимает готовую информацию, но и создает собственный продукт, проверяет гипотезы, анализирует ошибки и самостоятельно приходит к пониманию закономерностей. Это особенно важно для обоснования педагогического потенциала платформы Blockland.kz, поскольку работа с блочными алгоритмами, Python и Java предполагает активное конструирование знаний.

Ж. Уинг раскрывает вычислительное мышление как универсальный способ решения задач, основанный на декомпозиции, абстрагировании, алгоритмизации и оценке результата. В контексте настоящего исследования эти компоненты реализуются через построение алгоритма, выбор программной конструкции, сопоставление визуальных блоков с текстовым кодом и проверку результата.

К. Бреннан и М. Резник подчеркивают значение визуальных программных сред для развития вычислительного мышления, поскольку работа с блоками позволяет обучающимся сосредоточиться на логике решения задачи и постепенно переходить к более сложным формам программирования. Это положение непосредственно соотносится с функциональной структурой платформы Blockland.kz.

В казахстанской педагогической науке вопросы цифровизации образования, профессиональной подготовки будущих педагогов и применения интеллектуальных технологий в образовательном процессе рассматриваются в трудах Е. Ы. Бидайбекова, Н. Т. Ошановой, Г. К. Нургалиевой, А. О. Алдабергеновой, А. Е. Абылкасымовой и других исследователей. В частности, Р. Е. Абдуалиева и А. О. Алдабергенова рассматривают теоретические основания профессиональной подготовки учителей математики на основе нейронных сетей, что подтверждает актуальность использования современных цифровых и интеллектуальных технологий в педагогическом образовании.

Работы Е. Ы. Бидайбекова связаны с методикой обучения информатике и информатизацией образования. Исследования А. О. Алдабергеновой имеют значение для обоснования применения цифровых образовательных технологий в подготовке обучающихся и развитии их познавательных возможностей. А. Е. Абылкасымова раскрывает дидактико-методические основы математического образования, что важно для понимания роли логических операций в учебной деятельности. Г. К. Нургалиева рассматривает электронное обучение как условие инновационного развития образования.

В российской научно-педагогической традиции значительный вклад в изучение информатизации образования и методики обучения информатике внесли И. В. Роберт, Е. С. Полат, М. П. Лапчик, А. А. Кузнецов. И. В. Роберт обосновывает психолого-педагогические и технологические аспекты информатизации образования. Е. С. Полат рассматривает новые педагогические и информационные технологии как средство активизации учебной деятельности. М. П. Лапчик и А. А. Кузнецов исследуют методику обучения информатике и роль программирования в формировании учебных и интеллектуальных действий.

Особое значение для настоящего исследования имеют работы, посвященные влиянию цифровой среды на когнитивные функции школьников и студентов. Е. А. Авдеева и О. А. Корнилова рассматривают влияние цифровой электронной среды на когнитивные функции обучающихся, что позволяет учитывать не только развивающий потенциал цифровых ресурсов, но и возможные риски цифровизации: фрагментарность внимания, снижение глубины переработки информации и необходимость педагогического сопровождения цифрового обучения.

Для обоснования роли программирования в развитии мышления также значима работа М. В. Калининой «Программирование как средство развития алгоритмического мышления обучающихся». В данной работе программирование рассматривается как

средство формирования алгоритмического мышления, а алгоритмизация — как познавательно-проектирующая деятельность. Автор указывает, что решение задач на компьютере невозможно без создания алгоритма, а умения разрабатывать стратегию решения, выдвигать и проверять гипотезы, прогнозировать результат, анализировать и оптимизировать решение позволяют судить об уровне развития алгоритмического мышления обучающихся.

Нормативную основу исследования составляют государственные общеобязательные стандарты образования Республики Казахстан, типовые учебные программы по общеобразовательным предметам, а также документы, регулирующие содержание образования в системе технического и профессионального образования. Приказ Министра просвещения Республики Казахстан № 348 «Об утверждении государственных общеобязательных стандартов дошкольного воспитания и обучения, начального, основного среднего и общего среднего, технического и профессионального, послесреднего образования» определяет требования к содержанию образования, уровню подготовки обучающихся, ожидаемым результатам обучения и формированию функциональной грамотности.

Типовые учебные программы по предметам «Цифровая грамотность» и «Информатика» отражают необходимость формирования у обучающихся цифровых навыков, алгоритмического и вычислительного мышления. В начальной школе цифровая грамотность связана с первичным освоением алгоритмов, визуальных сред, простейших действий по созданию цифровых продуктов. В основной и старшей школе предмет «Информатика» обеспечивает переход к более сложному содержанию: алгоритмизации, программированию, работе с данными, моделированию и решению задач с использованием цифровых инструментов. Это соответствует логике платформы Blockland.kz, где обучающиеся переходят от блочных алгоритмов к программному коду на Python и Java.

Для системы технического и профессионального образования значимым является приказ Министра просвещения Республики Казахстан № 1 «Об утверждении типовых учебных программ цикла или модуля общеобразовательных дисциплин для организаций технического и профессионального образования». Данный нормативный документ определяет содержание общеобразовательных дисциплин для колледжей, включая дисциплину «Информатика», ориентированную на развитие логического, алгоритмического и вычислительного мышления обучающихся. Следовательно, применение платформы Blockland.kz имеет нормативное основание не только для университетской подготовки, но и для организаций технического и профессионального образования.

Таким образом, анализ научных источников и нормативных документов показывает, что цифровые образовательные технологии могут оказывать положительное влияние на когнитивные функции обучающихся только при условии их методически обоснованного применения. В данном исследовании платформа Blockland.kz рассматривается не как самостоятельный технический ресурс, а как дидактически организованная среда, в которой студенты выполняют действия анализа, сравнения, алгоритмизации, проверки, коррекции и рефлексии. Именно эти действия обеспечивают развитие внимания, памяти, логического, алгоритмического и критического мышления.

Содержание образовательного курса на основе Blockland.kz

В рамках экспериментальной работы был разработан и внедрен образовательный курс, основанный на конструкторах блочного программирования. Курс был направлен на постепенное формирование у студентов базовых программных, алгоритмических и когнитивных умений. Его содержание было построено с учетом логики перехода от визуального программирования к текстовому программному коду.

Курс включал следующие содержательные модули:

1. Введение в блочное программирование и цифровую среду Blockland.kz.
2. Линейные алгоритмы и последовательность действий.
3. Переменные, типы данных и простейшие операции.
4. Условные операторы и логические выражения.
5. Циклические алгоритмы.
6. Работа с простейшими структурами данных.
7. Сопоставление блочных конструкций с кодом на Python.
8. Сопоставление блочных конструкций с кодом на Java.
9. Решение задач в тренажере.
10. Анализ ошибок и оптимизация алгоритмов.
11. Итоговые практические задания и рефлексия учебных результатов.

Особенностью курса являлось сочетание визуального и текстового программирования.

На первом этапе студенты строили алгоритмы с помощью блоков, что позволяло сосредоточиться на логике решения задачи. На следующем этапе осуществлялось сопоставление блочной структуры с аналогичным кодом на Python и Java. Такой подход обеспечивал постепенный переход от наглядного представления алгоритма к формализованному программному коду и способствовал развитию логического, алгоритмического и вычислительного мышления.

Курс был интегрирован в учебный процесс в рамках практических занятий. Основной акцент был сделан на выполнении задач, требующих анализа условия, построения алгоритма, выбора соответствующих программных конструкций, проверки результата и исправления ошибок. Таким образом, курс был направлен не только на освоение основ программирования, но и на развитие когнитивных функций студентов.

Таблица 1 — Содержание образовательного курса на основе Blockland.kz

Модуль курса	Содержание работы	Развиваемые когнитивные функции
Введение в Blockland.kz	Знакомство с интерфейсом, блоками, тренажером и системой заданий	внимание, мотивация, ориентация в цифровой среде
Линейные алгоритмы	Построение последовательности действий	логическое мышление, алгоритмическое мышление
Переменные и типы данных	Работа с данными, значениями, простыми операциями	память, анализ, абстрагирование
Условные операторы	Использование условий и логических выражений	логическое мышление, критическое мышление
Циклы	Повторяющиеся действия, оптимизация решений	алгоритмическое мышление, скорость обработки информации
Структуры данных	Простые списки и наборы элементов	память, классификация, обобщение
Python-аналог	Сопоставление блоков с кодом Python	абстрагирование, перенос знаний
Java-аналог	Сопоставление блоков с кодом Java	анализ, сравнение, критическое мышление
Тренажер	Решение задач с автоматической проверкой	внимание, самостоятельность, скорость
Анализ ошибок	Поиск и исправление ошибок	критическое мышление, рефлексия
Итоговые задания	Комплексное решение задач	интеграция когнитивных функций

Материалы и методы исследования. Экспериментальное исследование проводилось в течение двух семестров на базе трех образовательных организаций: Жетысуского университета имени И. Жансугурова, Казахского национального женского педагогического университета и Талдыкорганского высшего политехнического колледжа. Выбор данных организаций был обусловлен необходимостью проверки эффективности платформы Blockland.kz в разных образовательных условиях: в университетской подготовке студентов и в системе технического и профессионального образования.

В исследовании приняли участие 157 студентов 2–3 курсов в возрасте 16–18 лет. Из них 79 человек вошли в экспериментальную группу, 78 человек — в контрольную группу.

Таблица 2 — Распределение респондентов по образовательным организациям

Образовательная организация	Экспериментальная группа	Контрольная группа	Всего
Жетысуский университет имени И. Жансугурова	30	30	60
Казахский национальный женский педагогический университет	25	24	49
Талдыкорганский высший политехнический колледж	24	24	48
Всего	79	78	157

Выборка была сформирована с учетом сопоставимости участников по возрасту, курсу обучения и исходному уровню подготовки. Контрольная и экспериментальная группы изучали близкое по содержанию учебное содержание, однако различались по способу организации учебной деятельности. Экспериментальная группа систематически использовала платформу Blockland.kz на занятиях, контрольная группа обучалась без регулярного применения данной платформы.

Платформа Blockland.kz включала следующие компоненты:

1. Блочное программирование — визуальная среда для построения алгоритмов из готовых программных блоков.
2. Аналоги кода на Python и Java — сопоставление блочной структуры алгоритма с текстовым программным кодом.
3. Тренажер — практические упражнения для закрепления линейных алгоритмов, ветвлений, циклов, переменных и базовых структур данных.
4. Набор задач — задания разного уровня сложности, направленные на развитие логического и алгоритмического мышления.
5. Автоматизированная проверка — фиксация правильности выполнения заданий и возможность анализа ошибок.

Содержание экспериментальной работы было соотнесено с нормативными требованиями к развитию цифровой грамотности, алгоритмического и вычислительного мышления. Это позволило рассматривать платформу Blockland.kz не как дополнительный технический ресурс, а как средство реализации образовательных результатов, предусмотренных современными требованиями к подготовке обучающихся.

Исследование проводилось в три этапа.

На первом, констатирующем этапе была проведена входная диагностика когнитивных функций студентов. Оценивались внимание, память, логическое мышление, алгоритмическое мышление, критическое мышление, скорость выполнения программных задач, учебная успеваемость и мотивация.

На втором, формирующем этапе студенты экспериментальной группы в течение двух семестров работали с платформой Blockland.kz. Учебная деятельность включала выполнение заданий по блочному программированию, сравнение блочной структуры с кодом на Python и Java, решение задач в тренажере, самостоятельную проверку результатов и анализ ошибок. Контрольная группа выполняла аналогичные по тематике задания в традиционном формате, без систематического использования платформы.

На третьем, контрольном этапе была проведена повторная диагностика по тем же показателям, что и на входном этапе. Это позволило сопоставить результаты до и после

эксперимента, сравнить динамику контрольной и экспериментальной групп, а также определить соответствие полученных результатов предварительным ожиданиям исследования.

Дополнительно после завершения формирующего этапа были проведены анкетирование и полуструктурированное интервью среди участников курса. Интервью включало вопросы о восприятии платформы, трудностях при выполнении заданий, удобстве перехода от блочного программирования к Python и Java, мотивационном влиянии платформы и предложениях по ее дальнейшему совершенствованию. Отдельно была собрана обратная связь от преподавателей, участвовавших в организации учебного процесса.

Диагностический инструментарий

Для оценки внимания использовались таблицы Шульте. Студентам предлагались таблицы 5×5 с числами от 1 до 25, расположенными в случайном порядке. Задача заключалась в последовательном нахождении чисел от 1 до 25 за минимальное время. Фиксировалось среднее время выполнения серии таблиц в секундах. Данный тест позволяет оценить концентрацию внимания, устойчивость зрительного поиска, скорость переключения и общий темп переработки информации. Чем меньше время выполнения задания, тем выше показатель внимания.

Для оценки памяти применялся тест на запоминание и воспроизведение учебной информации. Студентам предлагался список из 20 логически нейтральных слов и терминов, связанных с учебной деятельностью. После кратковременного предъявления участники должны были воспроизвести максимально возможное количество элементов. Оценивание осуществлялось по 20-балльной шкале: за каждый правильно воспроизведенный элемент начислялся 1 балл. Данный тест позволил оценить объем кратковременной памяти, точность воспроизведения и способность удерживать информацию после ограниченного времени предъявления.

Для диагностики логического мышления использовался адаптированный GALT-тест. В исследовании применялась версия, включающая задания на пропорциональное рассуждение, контроль переменных, вероятностное мышление, корреляционное мышление, комбинаторное рассуждение и сохранение логических зависимостей. Максимальный балл составил 20. Тест позволил определить уровень сформированности логических операций, необходимых для решения учебных и программных задач.

Алгоритмическое мышление оценивалось с помощью практических программных заданий. Студентам предлагались задачи на составление алгоритма, использование линейной структуры, условного оператора, циклов и простейших структур данных. Оценивание проводилось по 20-балльной шкале с учетом правильности алгоритма, последовательности действий, корректности результата и способности объяснить логику решения.

Критическое мышление оценивалось через задания на анализ и исправление ошибок. Студентам предлагались фрагменты алгоритмов или программных решений с намеренно допущенными ошибками. Необходимо было определить ошибку, объяснить ее причину и предложить корректный вариант решения. Максимальный балл составил 20. Данный инструмент позволил оценить способность обучающихся к анализу, проверке, аргументации и обоснованию выбранного решения.

Скорость выполнения программных задач определялась на основе среднего времени решения типовой задачи. Фиксировалось время от начала выполнения задания до получения корректного результата. Показатель измерялся в минутах.

Учебная успеваемость определялась на основе результатов текущих и итоговых заданий по 100-балльной шкале. Мотивация изучалась с помощью анкеты, включающей

вопросы об интересе к программированию, удобстве платформы, готовности выполнять задания, восприятию сложности и удовлетворенности учебным процессом. Ответы оценивались по пятибалльной шкале Лайкерта.

Для статистической обработки применялись методы описательной статистики, расчет средних значений, стандартного отклонения, сравнительный анализ показателей до и после эксперимента. Для проверки значимости различий использовался t-критерий Стьюдента для зависимых выборок внутри групп и t-критерий для независимых выборок при сравнении контрольной и экспериментальной групп. При интерпретации результатов статистически значимыми считались различия при $p < 0,05$.

Результаты исследования

Входная диагностика показала, что до начала эксперимента контрольная и экспериментальная группы имели близкий уровень когнитивных и учебных показателей. Это позволило рассматривать группы как сопоставимые для дальнейшего анализа.

Таблица 3 — Динамика когнитивных и учебных показателей студентов до и после эксперимента

Показатель	Экс. гр. до	Экс. гр. после	Контр. гр. до	Контр. гр. после
Внимание, таблицы Шульте, сек.	51,8	42,6	52,1	48,9
Память, балл из 20	11,4	16,2	11,5	13,0
Логическое мышление, GALT, балл из 20	10,8	15,9	10,9	12,4
Алгоритмическое мышление, балл из 20	9,8	16,1	9,9	12,7
Критическое мышление, балл из 20	10,6	15,2	10,7	12,3
Скорость выполнения программных задач, мин.	14,3	9,7	14,1	12,5
Учебная успеваемость, балл из 100	68,4	82,7	67,9	74,2
Учебная мотивация, балл из 5	3,24	4,31	3,21	3,56

По результатам таблиц Шульте в экспериментальной группе среднее время выполнения задания сократилось с 51,8 до 42,6 секунды. Улучшение составило 9,2 секунды. В контрольной группе показатель изменился с 52,1 до 48,9 секунды, то есть улучшение составило 3,2 секунды. Более выраженная динамика в экспериментальной группе свидетельствует о положительном влиянии платформы Blockland.kz на концентрацию внимания, скорость зрительного поиска и переключение между элементами.

Результаты теста на память показали, что в экспериментальной группе средний балл увеличился с 11,4 до 16,2 из 20. В контрольной группе рост составил с 11,5 до 13,0 балла. Это позволяет сделать вывод о том, что регулярное выполнение программных заданий способствует развитию памяти, поскольку студенту необходимо удерживать в сознании условие задачи, последовательность действий, значения переменных и промежуточные результаты.

По адаптированному GALT-тесту средний показатель логического мышления в экспериментальной группе повысился с 10,8 до 15,9 балла из 20. В контрольной группе показатель вырос с 10,9 до 12,4 балла. Наиболее заметная динамика была выявлена по заданиям, связанным с комбинаторным рассуждением, контролем переменных и

установлением логических зависимостей. Это подтверждает, что работа с алгоритмами и программными задачами активизирует логические операции анализа, сравнения, обобщения и причинно-следственного объяснения.

Алгоритмическое мышление в экспериментальной группе повысилось с 9,8 до 16,1 балла. В контрольной группе показатель увеличился с 9,9 до 12,7 балла. Данная динамика является закономерной, поскольку содержание платформы Blockland.kz непосредственно связано с построением алгоритмов, использованием условий, циклов, переменных и последовательной проверкой результата.

Показатель критического мышления в экспериментальной группе вырос с 10,6 до 15,2 балла. В контрольной группе рост составил с 10,7 до 12,3 балла. Это объясняется тем, что студенты экспериментальной группы регулярно анализировали ошибки, сравнивали разные способы решения, проверяли корректность алгоритма и обосновывали выбранный вариант.

Скорость выполнения программных задач в экспериментальной группе улучшилась с 14,3 до 9,7 минуты. В контрольной группе показатель изменился с 14,1 до 12,5 минуты. Следовательно, использование платформы способствовало не только повышению качества решения задач, но и ускорению выполнения алгоритмических действий.

Учебная успеваемость студентов экспериментальной группы повысилась с 68,4 до 82,7 балла из 100. В контрольной группе рост составил с 67,9 до 74,2 балла. Это показывает, что развитие когнитивных функций сопровождалось улучшением учебных результатов.

Для более детального анализа была проведена дифференциация результатов по образовательным организациям.

Таблица 4 — Динамика среднего интегрального показателя когнитивного развития по образовательным организациям

Образовательная организация	Экс. до	гр. после	Экс. до	гр. после	Контр. до	гр. после
Жетысуский университет имени И. Жансугурова	58,6	80,4	58,9	68,7		
Казахский национальный женский педагогический университет	57,9	79,1	58,1	67,5		
Талдыкорганский высший политехнический колледж	56,8	76,9	57,0	65,8		

Интегральный показатель был рассчитан на основе усреднения нормированных результатов по вниманию, памяти, логическому мышлению, алгоритмическому мышлению, критическому мышлению и скорости выполнения заданий. Наибольший прирост был выявлен в экспериментальной группе Жетысуского университета имени И. Жансугурова: показатель увеличился с 58,6 до 80,4 балла. В Казахском национальном женском педагогическом университете показатель вырос с 57,9 до 79,1 балла. В Талдыкорганском высшем политехническом колледже также была зафиксирована положительная динамика — с 56,8 до 76,9 балла.

Полученные данные показывают, что положительное влияние платформы Blockland.kz проявилось во всех трех образовательных организациях. При этом различия в уровне прироста могут быть связаны с исходной подготовкой студентов, особенностями образовательной программы, количеством практических занятий и уровнем самостоятельности обучающихся.

Сопоставление ожидаемых и полученных результатов

Одной из задач исследования являлось сопоставление полученных экспериментальных данных с предварительными ожиданиями проекта. Такое сравнение позволило определить, какие положения гипотезы подтвердились полностью, какие — частично, а какие требуют дальнейшей проверки.

Таблица 5 — Сопоставление ожидаемых и полученных результатов исследования

Ожидаемый результат	Полученный результат	Степень подтверждения
Повышение концентрации внимания студентов при выполнении учебных заданий	Среднее время выполнения таблиц Шульце в экспериментальной группе сократилось с 51,8 до 42,6 секунды	Подтверждено
Улучшение показателей памяти за счет регулярного выполнения алгоритмических заданий	Средний балл по тесту памяти увеличился с 11,4 до 16,2 балла из 20	Подтверждено
Развитие логического мышления через работу с алгоритмами и программными задачами	Показатель GALT повысился с 10,8 до 15,9 балла из 20	Подтверждено
Развитие алгоритмического мышления через блочное программирование, Python и Java	Показатель алгоритмического мышления вырос с 9,8 до 16,1 балла из 20	Подтверждено
Развитие критического мышления через анализ ошибок и сравнение решений	Показатель критического мышления вырос с 10,6 до 15,2 балла из 20	Подтверждено
Повышение учебной мотивации студентов	Средний показатель мотивации вырос с 3,24 до 4,31 балла из 5	Подтверждено
Полное отсутствие трудностей при переходе от блоков к текстовому коду	35,4% студентов отметили трудности при переходе от блоков к Python и Java	Подтверждено частично
Повышение учебной успеваемости	Средний показатель успеваемости в экспериментальной группе повысился с 68,4 до 82,7 балла	Подтверждено

Сопоставление показало, что основные ожидания исследования подтвердились. Наиболее выраженная положительная динамика была выявлена по логическому и алгоритмическому мышлению, что соответствует содержательной направленности платформы Blockland.kz. Частично подтвердилось ожидание, связанное с беспроблемным переходом от блочного программирования к текстовому коду. Несмотря на общую положительную оценку платформы, часть студентов отметила необходимость дополнительных пояснений при переходе к Python и Java. Данный результат имеет практическую значимость, поскольку указывает на конкретное направление дальнейшего совершенствования платформы.

Результаты опроса студентов экспериментальной группы

После завершения формирующего этапа был проведен опрос студентов экспериментальной группы. В анкетировании приняли участие 79 респондентов. Анкета включала вопросы, направленные на выявление отношения студентов к платформе Blockland.kz, удобства ее использования, влияния на мотивацию, понимание программирования и трудностей, возникших в процессе работы. Ответы фиксировались по пятибалльной шкале, а также в формате выбора утверждений.

Таблица 6 — Результаты опроса студентов экспериментальной группы

Показатель опроса	Количество студентов	Доля, %
Платформа помогла лучше понять логику алгоритмов	72	91,1 %
Блочное программирование облегчило освоение программирования	70	88,6 %
Сопоставление блоков с Python и Java было полезным	67	84,8 %
Работа с тренажером повысила интерес к занятиям	64	81,0 %
Набор задач способствовал самостоятельной работе	66	83,5 %
Платформа помогла быстрее находить ошибки в алгоритмах	62	78,5 %
Интерфейс платформы был понятным и удобным	69	87,3 %
Возникали трудности при переходе от блоков к текстовому коду	28	35,4 %
Требовалась более подробная обратная связь при ошибках	22	27,8 %
Возникали технические трудности при работе с платформой	10	12,7 %

Результаты опроса показывают, что большинство студентов положительно оценили использование платформы Blockland.kz. Наиболее высокий показатель был получен по утверждению о том, что платформа помогла лучше понять логику алгоритмов: с этим согласились 72 студента, что составило 91,1% от общего числа участников экспериментальной группы. Это подтверждает, что визуальное представление программных конструкций способствует осознанному восприятию алгоритмической структуры задачи.

Также 88,6% студентов отметили, что блочное программирование облегчило освоение программирования. Данный результат особенно важен, поскольку на начальном этапе изучения программирования обучающиеся часто сталкиваются с трудностями, связанными с синтаксисом языка, структурой кода и пониманием логики выполнения команд. Блочная форма представления алгоритма позволяет снизить эти трудности и сосредоточить внимание на смысловой стороне решения.

Положительно была оценена возможность сопоставления блоков с Python и Java. Этот компонент платформы оказался полезным для 84,8% студентов. Следовательно, связь между визуальным алгоритмом и текстовым программным кодом помогает обучающимся постепенно переходить от наглядного уровня понимания к более формализованному программированию.

Работа с тренажером повысила интерес к занятиям у 81,0% студентов. Это свидетельствует о мотивационном потенциале платформы. Практические задания, возможность самостоятельной проверки и постепенное усложнение содержания способствуют повышению вовлеченности обучающихся в учебный процесс.

При этом опрос позволил выявить и определенные трудности. Так, 35,4% студентов указали, что у них возникали сложности при переходе от блочного программирования к текстовому коду. Это показывает необходимость включения в платформу дополнительных

пояснений, пошаговых комментариев и заданий, направленных именно на сопоставление блоков с синтаксисом Python и Java. Кроме того, 27,8% респондентов отметили потребность в более подробной обратной связи при ошибках. Следовательно, дальнейшее развитие платформы должно быть связано с расширением диагностических и объяснительных функций.

В целом результаты опроса подтверждают, что платформа Blockland.kz воспринимается студентами как удобный, понятный и полезный инструмент для изучения программирования и развития когнитивных функций. Особенно значимыми оказались такие характеристики, как визуальность, практическая направленность, наличие тренажера, возможность самостоятельной работы и связь блочных конструкций с языками Python и Java.

Результаты интервью студентов и преподавателей

Для получения качественных данных после завершения образовательного курса было проведено полуструктурированное интервью с участниками экспериментальной группы. Интервью позволило уточнить, какие аспекты платформы студенты считают наиболее полезными, какие трудности возникали в процессе обучения и какие предложения они считают важными для дальнейшего совершенствования Blockland.kz.

По результатам интервью студенты отметили, что блочная структура облегчает первичное понимание алгоритма. По их мнению, визуальное представление команд помогает быстрее понять последовательность действий, логику условия и структуру цикла. Особенно полезным студенты назвали сопоставление блоков с кодом на Python и Java, поскольку это позволило им увидеть связь между визуальной моделью и текстовым программированием.

Одновременно участники интервью указали, что переход от блочного программирования к текстовому коду не всегда является простым. Наиболее частыми трудностями стали понимание синтаксиса Python и Java, необходимость правильного написания команд, работа с ошибками и недостаток подробных подсказок при неправильном решении. Студенты предложили добавить больше пошаговых объяснений, примеров с комментариями и заданий разного уровня сложности.

Дополнительно была проведена оценка обратной связи от преподавателей, участвовавших в организации учебного процесса. Преподаватели отметили, что использование платформы Blockland.kz позволило повысить активность студентов на практических занятиях, ускорить процесс проверки базовых алгоритмических действий и сделать более наглядным переход от блочного программирования к текстовому коду на Python и Java. Вместе с тем преподаватели обозначили направления дальнейшего совершенствования платформы: расширение системы автоматизированной обратной связи, добавление методических рекомендаций для преподавателя, включение заданий разных уровней сложности и создание аналитического модуля для отслеживания индивидуальной динамики обучающихся.

Таким образом, результаты интервью подтвердили данные анкетирования и позволили выявить конкретные направления улучшения образовательной платформы. Качественный анализ показал, что платформа имеет высокий дидактический потенциал, однако для повышения ее эффективности необходимо усилить методическую поддержку перехода от визуального программирования к текстовому коду.

Обсуждение результатов

Полученные результаты позволяют сделать вывод о положительном влиянии платформы Blockland.kz на развитие когнитивных функций студентов. Наиболее выраженная динамика была выявлена по показателям логического и алгоритмического мышления. Это объясняется содержательной спецификой платформы, поскольку работа с программными

задачами требует анализа условий, построения алгоритма, выбора программной конструкции, проверки результата и исправления ошибок.

Результаты исследования согласуются с положениями С. Пейперта о том, что программирование может быть средством развития мышления, поскольку обучающийся в процессе работы создает собственный продукт и активно конструирует знания. Также результаты соотносятся с идеями Ж. Уинг о вычислительном мышлении, включающем декомпозицию, алгоритмизацию, абстрагирование и оценку результата. Подходы К. Бреннан и М. Резника к развитию вычислительного мышления в визуальных программных средах также подтверждают значимость блочного программирования как средства вовлечения обучающихся в активную интеллектуальную деятельность.

Существенную роль в интерпретации результатов играет работа М. В. Калининой, где подчеркивается, что алгоритмическое мышление связано с умением разрабатывать стратегию решения задачи, выдвигать и проверять гипотезы, прогнозировать результат, анализировать и находить рациональные способы решения. Именно такие действия выполнялись студентами экспериментальной группы при работе с платформой Blockland.kz.

Положительная динамика внимания может быть объяснена тем, что выполнение заданий на платформе требует постоянной концентрации, контроля последовательности действий и сопоставления визуальных блоков с программным кодом. Развитие памяти связано с необходимостью удерживать в сознании условие задачи, структуру алгоритма, значения переменных и промежуточные результаты. Рост критического мышления объясняется тем, что студенты регулярно анализировали ошибки, сравнивали варианты решения и обосновывали выбранный алгоритм.

С учетом исследований Е. А. Авдеевой и О. А. Корниловой важно отметить, что цифровая среда может иметь неоднозначное влияние на когнитивные функции обучающихся. С одной стороны, она расширяет возможности обучения, визуализации и интерактивной практики. С другой стороны, при недостаточной методической организации цифровая среда может усиливать поверхностное восприятие информации и фрагментарность внимания. Поэтому результаты настоящего исследования следует связывать не только с применением платформы как технического инструмента, но и с ее педагогически направленным использованием на занятиях.

Казахстанские и российские исследования в области информатизации образования также подтверждают необходимость методически обоснованного применения цифровых технологий. В трудах Е. Ы. Бидайбекова, Г. К. Нургалиевой, И. В. Роберт, Е. С. Полат, М. П. Лапчика и А. А. Кузнецова подчеркивается, что цифровые технологии становятся эффективными только тогда, когда они встроены в содержание обучения и направлены на активизацию учебной деятельности. Исследования А. О. Алдабергеновой и Р. Е. Абдуалиевой также позволяют рассматривать интеллектуальные и цифровые технологии как важный компонент современной подготовки будущих педагогов.

Нормативные документы Республики Казахстан подтверждают практическую значимость полученных результатов. Требования ГОСО РК, типовых учебных программ по цифровой грамотности и информатике, а также программ для организаций технического и профессионального образования ориентируют педагогическую практику на развитие функциональной грамотности, цифровых навыков, логического, алгоритмического и вычислительного мышления. В этом контексте платформа Blockland.kz может рассматриваться как инструмент, соответствующий современным образовательным приоритетам и способствующий достижению ожидаемых результатов обучения.

Положительная динамика по всем трем образовательным организациям показывает, что платформа Blockland.kz может использоваться как в университетской среде, так и в системе технического и профессионального образования. При этом различия в приросте

показателей между Жетысуским университетом, Казахским национальным женским педагогическим университетом и Талдыкорганским высшим политехническим колледжем могут быть связаны с исходным уровнем подготовки студентов, регулярностью выполнения заданий и особенностями образовательной программы.

Результаты опроса и интервью студентов также подтверждают развивающий потенциал платформы. Большинство респондентов отметили, что блочное программирование облегчает понимание логики алгоритмов, а сопоставление блоков с Python и Java помогает лучше осваивать программирование. Вместе с тем выявленные трудности при переходе от блоков к текстовому коду показывают необходимость дальнейшего совершенствования платформы: добавления пошаговых пояснений, расширенной обратной связи и адаптивных заданий.

Вместе с тем исследование имеет определенные ограничения. Во-первых, эксперимент проводился в течение двух семестров, что позволяет выявить учебную динамику, но не дает полного представления о долгосрочном сохранении результатов. Во-вторых, на результаты могли повлиять исходный уровень цифровой грамотности студентов, их интерес к программированию, особенности преподавания и регулярность выполнения заданий. В-третьих, мотивация и отношение к платформе оценивались на основе анкетирования и интервью, что предполагает наличие субъективного компонента. В-четвертых, исследование проводилось в трех образовательных организациях, поэтому в дальнейшем целесообразно расширить выборку и включить другие регионы.

Рекомендации по совершенствованию платформы Blockland.kz

На основе количественных результатов исследования, данных анкетирования, интервью студентов и обратной связи преподавателей были сформулированы следующие рекомендации по дальнейшему совершенствованию платформы Blockland.kz.

Во-первых, необходимо расширить систему обратной связи при выполнении заданий. В настоящее время для студентов важно получать не только информацию о правильности или неправильности ответа, но и пояснение причины ошибки. Целесообразно добавить автоматические подсказки, пошаговый разбор решения, указание на тип ошибки и рекомендации по ее исправлению.

Во-вторых, следует усилить блок перехода от блочного программирования к текстовому коду на Python и Java. Часть студентов испытывала трудности при переходе от визуальных блоков к синтаксису языков программирования. Поэтому необходимо включить дополнительные примеры с комментариями, сопоставительные таблицы «блок — код», пошаговые объяснения и задания на преобразование блочного алгоритма в текстовую программу.

В-третьих, рекомендуется добавить задания разных уровней сложности. Это позволит учитывать индивидуальные различия студентов, их исходный уровень подготовки и темп освоения материала. Задания могут быть разделены на базовый, средний и продвинутый уровни.

В-четвертых, целесообразно разработать аналитический модуль для преподавателя. Такой модуль может фиксировать количество выполненных заданий, типичные ошибки, время выполнения, динамику успешности, уровень сложности заданий и индивидуальный прогресс каждого студента.

В-пятых, необходимо усилить блок заданий на критическое мышление и анализ программных ошибок. Такие задания способствуют развитию умения проверять собственные решения, сравнивать разные варианты алгоритмов, находить ошибки и обосновывать выбранный способ решения.

В-шестых, рекомендуется подготовить методические рекомендации для преподавателей по использованию платформы на занятиях. В них целесообразно включить

описание модулей курса, примеры заданий, рекомендации по организации практических занятий, критерии оценивания и способы работы с результатами диагностики.

В-седьмых, целесообразно развивать адаптивность платформы. На основе результатов выполнения заданий система может предлагать студенту индивидуальную траекторию: дополнительные упражнения при затруднениях, более сложные задания при успешном выполнении базового уровня и повторение тем, по которым были допущены ошибки.

Реализация данных рекомендаций позволит повысить педагогическую эффективность платформы Blockland.kz, усилить ее диагностические и обучающие функции, а также расширить возможности использования в университетах и организациях технического и профессионального образования.

Заключение

Проведенное исследование показало, что образовательная платформа Blockland.kz обладает значительным педагогическим потенциалом для развития когнитивных функций студентов. Систематическое применение платформы в течение двух семестров способствовало положительной динамике внимания, памяти, логического, алгоритмического и критического мышления, скорости выполнения программных задач, учебной мотивации и успеваемости.

Наиболее выраженные изменения были выявлены по показателям логического и алгоритмического мышления. Это связано с тем, что работа с платформой требует от студентов анализа условий, построения алгоритмов, проверки результата, поиска ошибок и обоснования решений. Положительная динамика внимания и памяти объясняется необходимостью сосредоточенного выполнения заданий, удержания в памяти структуры алгоритма и последовательности программных действий.

Сопоставление ожидаемых и полученных результатов показало, что основные положения гипотезы исследования подтвердились. Платформа Blockland.kz оказала положительное влияние на целевые когнитивные параметры студентов. Частично подтвердилось ожидание, связанное с отсутствием трудностей при переходе от блочного программирования к текстовому коду, поскольку часть студентов указала на необходимость дополнительных пояснений и методической поддержки при освоении Python и Java.

Результаты опроса подтвердили положительное отношение студентов к платформе Blockland.kz. Большинство респондентов отметили, что блочное программирование облегчает понимание алгоритмов, сопоставление блоков с Python и Java помогает лучше осваивать программирование, а тренажер и набор задач повышают интерес к занятиям. Результаты интервью студентов и преподавателей позволили уточнить направления дальнейшего совершенствования платформы: расширение обратной связи, добавление адаптивных заданий, разработка аналитического модуля и усиление методического сопровождения.

Нормативная значимость исследования заключается в том, что результаты соотносятся с современными требованиями образовательной политики Республики Казахстан, направленными на развитие функциональной грамотности, цифровой грамотности, алгоритмического и вычислительного мышления обучающихся. В этом отношении платформа Blockland.kz может быть использована как практический инструмент реализации данных требований в образовательном процессе.

Теоретическая значимость исследования заключается в уточнении возможностей блочного программирования как средства развития когнитивных функций студентов. Практическая значимость состоит в том, что результаты исследования могут быть использованы при разработке цифровых образовательных платформ, организации занятий по программированию, проектировании методик развития логического и алгоритмического

мышления обучающихся, а также при создании образовательных курсов на основе конструкторов блочного программирования.

Перспективы дальнейших исследований связаны с расширением выборки, проведением долгосрочного мониторинга результатов, сравнением эффективности различных цифровых платформ, разработкой адаптивных заданий, созданием аналитического модуля для преподавателей и более детальным анализом влияния отдельных компонентов платформы Blockland.kz на разные когнитивные функции.

Финансирование. Данное исследование выполнено в рамках проекта грантового финансирования для молодых ученых по научным и/или научно-техническим проектам «Жас ғалым» по приоритетному направлению «Интеллектуальный потенциал страны», реализуемого Комитетом науки Министерства науки и высшего образования Республики Казахстан. Тема проекта: «Исследование и применение блочных конструкторов программирования для улучшения когнитивных навыков у обучающихся», ИРН AP22688217.

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Philological Sciences

English Non-equivalent and Partially Equivalent Vocabulary in Georgian Translation

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Abstract

This paper examines the translation strategies most frequently employed by Georgian translators in rendering non-equivalent and partially equivalent lexical units from English into Georgian. The transfer of such culture-bound lexical items constitutes a significant challenge in translation studies and has attracted considerable scholarly attention. The lexical units analysed in this study comprise realia and quasi-realialia. Realialia refer to culture-specific referents that lack direct equivalents in the target language, whereas quasi-realialia denote referents for which target-language equivalents exist and share the same primary characteristics but differ in certain secondary or culturally marked features. The translation of non-equivalent and partially equivalent lexical units presents translators with a dual challenge: ensuring the comprehensibility of the target text while simultaneously preserving the national and cultural meanings embedded in the source text. To reconcile these competing demands, translators employ a range of strategies designed to facilitate effective intercultural communication. The choice of a particular strategy is determined by the specific characteristics of the communicative situation, including linguistic, cultural, and pragmatic considerations. The study is based on a comparative analysis of English-language literary prose and its Georgian translations. The findings demonstrate that, in translating realialia, Georgian translators most frequently resort to such strategies as transcription, calquing, generalization, descriptive translation, omission and cultural substitution. The analysis highlights the pivotal role of strategic decision-making in balancing semantic accuracy, cultural specificity, and reader accessibility, thereby contributing to the successful mediation between source and target cultures.

Key Words: non-equivalent and equivalent lexical units, realialia, quasi-realialia, translation strategies.

Introduction

The translation of non-equivalent and partially equivalent vocabulary constitutes one of the central challenges in the transfer of the national and cultural specificity of a source text into a target language. In addressing this challenge, translators draw upon their knowledge of translation theory, linguistic competence, cultural background knowledge, professional experience and intuition. Taking into account the broader contextual framework and operating on the basis of a synthesis of the cultures of the source and target languages they select the strategy that most effectively fulfils the communicative and cultural objectives of the translation.

Non-equivalent and partially equivalent vocabulary encompasses both realialia and quasi-realialia. Realialia refer to culture-specific concepts and objects that lack direct equivalents in the target language, whereas quasi-realialia denote referents for which target-language equivalents exist and share the same essential characteristics but differ in certain secondary or culturally marked

features. The presence of realia and quasi-realialia further complicates the translator's task of rendering the source text accurately and comprehensively while preserving its stylistic, expressive and cultural nuances. In this context, the notion of translational completeness may be understood as the preservation of the unity of form and content despite the shift to a different linguistic system.

Methods

The study employs a comparative and descriptive approach to translation analysis. The research is based on the juxtaposition of English-language literary texts and their Georgian translations. Through qualitative analysis instances of realia and quasi-realialia are identified and classified according to the translation strategies applied. Contextual and functional analyses are used to explain translators' choices and to assess their effectiveness in preserving the cultural specificity of the source text while ensuring comprehensibility for the target audience.

Results and Discussion

The concept of equivalence has traditionally been regarded as one of the fundamental issues in translation theory. Early scholars such as Nida (1964) and Catford (1965) explored the relationship between source and target texts, emphasizing the difficulties involved in transferring meaning across linguistic and cultural boundaries. The problem of non-equivalence received further attention in the works of Baker (1992), who examined the various forms of non-equivalence at the word level and proposed a range of strategies for addressing lexical gaps between languages.

The notion of realia was developed most comprehensively by Vlahov and Florin (1980), who defined realia as lexical units denoting objects, phenomena, institutions, customs, and other elements specific to a particular culture and lacking direct equivalents in another language. Closely related to realia are quasi-realialia, which denote referents that possess partial equivalents in the target culture but differ in certain culturally significant features. Such lexical units present additional challenges because apparent equivalence may obscure important semantic and cultural distinctions. The cultural dimension of translation has also been explored and translation strategies for rendering culture-specific items have been examined by Newmark (1988), Vinay and Darbelnet (1995), Venuti (1995), Franco Aixelá (1996), etc.

Despite extensive international research on culture-specific items, studies focusing on the translation of realia and quasi-realialia between English and Georgian remain relatively limited. Consequently, further investigation is required to identify the strategies most frequently employed by Georgian translators and to evaluate their effectiveness in preserving cultural specificity while ensuring the accessibility of the translated text. The present study seeks to contribute to this area of research through a comparative analysis of English literary texts and their Georgian translations.

One of the most prevalent strategies - **Transcription** - refers to the transfer of a lexical unit from one language into another by preserving the phonetic form of the original to the maximum, using the graphic means of the language. When successfully transcribing realia, the translator manages to transfer both the content and the national-cultural connotation from one language to another:

"Twas hasty **puddin'**, as ye say," said her husband, "and hurry-up turnips..." (O. Henry, *Between Rounds*).

„ეს ნაჩქარევად მომზადებული **პუდინგისა** და თაღგამის შეჭამანდის ბრალია“ („es nachkarevad momzadebuli **p'udingisa** da talgamis shech'amandis bralia“ - Translator M. Natadze).

In the aforementioned example the English realia "pudding" is a referent that has been known internationally for quite a long time; As a result, the reader is likely to perceive it correctly.

Nevertheless, if there is a possibility that the meaning is uncertain for the reader, the translator can add the relevant definition to the translation:

“Grilled steak and onions, Angelo, fried potatoes, and a bottle of **Bass**. Give it me in a silver tankard”. (W.S. Maugham, Theatre).

„გრილზე შემწვარი სტეიკი ხახვით, ენჯელოუ, შემწვარი კარტოფილი და ერთი ბოთლი „ბასი“, ოღონდ სასმელი ვერცხლის ტოლჩით მომიტანე“ („grilze shemts'vari st'eik'i khakhvit, enjelou, shemts'vari k'art'opili da erti botli „basi“, oghond sasmeli vertskhlis t'olchit momit'ane“ - Translator N. Chubinidze); The definition is provided in the footnotes: „basi” – the name of the beer.

It should also be noted that in case of unsuccessful transcription, the reader may be exposed to serious difficulties. The use of excessive number of transcribed realia is likely to have a negative impact on the process of comprehending the text. On the other hand, an excessive number of comments prevents the reader from concentrating on the text. Therefore, if possible, the translator chooses different ways of transferring realia into the target language.

One of the most prevalent translation methods is *calquing* - the transfer of realia from one language to another by translating its components, while maximally preserving the semantics of each component:

“Among other public buildings in a certain town... there is one anciently common to most towns, great or small: to wit, a **workhouse**.”(Ch. Dickens, Oliver Twist).

„ერთერთ ქალაქში... მრავალრიცხოვანი საჯარო ნაგებობის გვერდით იდგა დაწესებულ ება. ამ დაწესებულებას თითქმის ყველა დიდ თუ პატარა ქალაქში შეხვდებოდით და მას **შრომის სახლი** ეწოდებოდა“ („ertert kalakshi... mravalritskhovani sajaro nagebobis gverdit idga dats'esebuleba. am dats'esebulebas titkmis qvela did tu p'at'ara kalakshi shekhvdebodit da mas **shromis sakhli** ets'odeboda“ - Translator E. Sumbatashvili).

The "workhouse" is an English historical realia - a shelter for the socially disadvantaged, which is often found in English prose. Calquing this realia has become a tradition in translation. However, the reader who encounters it for the first time may need an appropriate explanation.

The strategy of calquing is often used when translating proper names:

“If it were me - I mean I - well, I should get somebody to put in the **Morning Paper** the news that Jane and Michael and John and Barbara Banks (to say nothing of their mother) require the best possible Nannie at the lowest possible wage and at once.” (P.L. Travers, Mary Poppins).

„შენს ადგილას მე „დილის გაზეთში“ ასეთ განცხადებას გამოვაქვეყნებდი: „ჯეინ და მაიკლ, ჯონ და ბარბარა ბენქსებს (მათ დედაზე რომ არაფერი ვთქვათ) სასწრაფოდ სჭირდებათ ყველაზე კარგი გადია, რომელიც ყველაზე მცირე ხელფასს დასჯერდება!“ („shens adgilas me „dilis gazetshi“ aset gantskhadebas gamovakveqnebd: „jein da maik'l, jon da barbara benksebs (mat dedaze rom araperi vtkvat) sasts'rapod sch'irdebat qvelaze k'argi gadia, romelits qvelaze mtsire khelpass dasjerdeba!“ - Translator L. Gogokhia).

Typically, the transcription method is most often applied when translating the titles of periodicals:

“He was reading the **Atlantic Monthly**” (J.Salinger, The Catcher in the Rye).

„ატლანტიკ მანთლისა“ კითხულობდა“ („at'lant'ik' mantlisa“ k'itkhulobda“ - Translator V. Chelidze).

However, in the case of "Mary Poppins", the number of instances of transcription is minimized since the text is intended for young readers.

The same goes for the following example where the name of a street is calqued:

“The day after the birthday party the Starling... came back to Number Seventeen, **Cherry-Tree Lane**” (P.L. Travers, Mary Poppins).

„სწორედ ლხინის მეორე დღეს დაბრუნდა... შოშია ალუბლის შესახვევის ჩვიდმეტ ნომერ სახლში“ („sts'ored lkhinis meore dghes dabrunდა... shoshia alublis shesakhvevis chvidmet' nomer sakhlishi“ - Translator L. Gogokhia).

Generalization is also a widespread technique, which implies replacement of a lexical unit having a relatively limited meaning with a lexical unit of a broader semantic range:

“They... found their tastes in art, chicory salad and **bishop sleeves** so congenial that the joint studio resulted” (O. Henry, The Last Leaf).

„ისინი სავსებით ეთანხმებოდნენ ერთმანეთს ხელოვნების საკითხებში; ორივეს მოსწონდა ვარდ-კაჭაჭის სალათი და **ჩაცმულობის** მხრივაც მათი გემოვნება ერთმანეთს ეხამებოდა, რის შედეგადაც გადაწყვიტეს მოეწყოთ ზიარი სახელოსნო“ („isini savsebit etankhmebodnen ertmanets khelovnebis sak'itkhebshi; orives mosts'onდა vard-k'ach'ach'is salati da **chatsmulobis** mkhrivats mati gemovneba ertmanets ekhameboda, ris shedegadats gadats'qvit'es moets'qot ziari sakhelosno“ - Translator M. Natadze).

In the given example the realia reflecting the specific design of a sleeve is replaced in the translation with a generalized form – “clothes”.

In the next example of generalization the name of the resort town Bournemouth is changed to the general form – “summer/holiday/country home” – to make it easier for young readers to understand:

“The day after the birthday party the Starling, who had been away on holiday at **Bournemouth**, came back to Number Seventeen, Cherry-Tree Lane” (P.L. Travers, Mary Poppins).

„სწორედ ლხინის მეორე დღეს დაბრუნდა **აგარაკიდან** შოშია ალუბლის შესახვევის ჩვიდმეტ ნომერ სახლში“ („sts'ored lkhinis meore dghes dabrunდა **agarak'idan** shoshia alublis shesakhvevis chvidmet' nomer sakhlishi“ - Translator L. Gogokhia).

However, it is worthy of note that the translator almost always transfers toponyms into the translation since they are significant cultural markers.

Generalization is effective when realia in the original are not emphasized by the author. But if realia are essential for the context, the generalized form is likely to result in the complete loss of the national and cultural semantic component of the original.

Another strategy – **descriptive translation** – implies replacement of realia with their definitions:

“Sorry we're so late,” said Roger. “There was a filthy crowd and we had to wait on nearly every **tee**. We **halved the match**” (W.S. Maugham, Theatre).

„გვაპატიეთ, რომ დავაგვიანეთ, – თქვა როჯერმა, – მინდორზე უამრავი საძაგელი ადამიანი ტრიალებდა და თითოეული **ბურთის ნიშანთან** ლოდინი გვიწევდა. **თანაბრად დავარტყით**“ („gvap'at'iet, rom davagvianet, – tkva rojerma, – mindorze uamravi sadzageli adamiani t'rialebda da titoeuli **burtis nishantan** lodini gvits'evda. **tanabrad davart'qit**“ - Translator N. Chubinidze).

The word “tee” and the phrase “halve the match” belong to sports terms, more specifically, golf terminology, which is extremely popular in Britain and is easily understood by British readers. Nonetheless, in the Georgian translation it became necessary to use the descriptive method.

There is another example of descriptive translation:

“Michael, why don't you let that flat in **the mews** to Tom?” (W.S. Maugham, Theatre).

„მაიკლ, ტომი ხომ არ შევუშვავთ იმ **ბინაში, გარაჟების თავზე?**“ („maik'l, t'omi khom ar shevushvat im **binashi, garazhebis tavze?**“ - Translator N. Chubinidze).

In this case we are dealing with the British realia of “mews”. It is a two-story building that once served as a stable. Nowadays, garages or warehouses are located on the first floor, and residential apartments are located on the second floor.

Sometimes, along with using the descriptive translation method, additional comments are necessary:

“Tom went to Eastbourne with his family for Christmas. Julia had two performances on **Boxing day**”... (W.S. Maugham, Theatre).

„ტომი სამობაოდ ისტბორნში ჩავიდა, მშობლებთან. ჯულიას **საჩუქრების დღეს** ორი წარმოდგენა ჰქონდა...” („t'omi sashobaod ist'bornshi chavida, mshoblebtan. julias **sachukrebis dghes** ori ts'armodgena hkonda...” - Translator N. Chubinidze).

Additional comments are provided in the footnotes: "Boxing Day - the second day of Christmas, when people give each other presents."

Descriptive translation enables the translator to preserve the semantics of realia to the maximum. However, even in this case it is necessary to consider the principle of the golden middle. Any developed language has the means to present realia of any different language, but the excessive amount of explanations deter the reader's perception of the text.

The next strategy to transfer realia from one language to another is omission:

“There were pills and medicine all over the place, and everything smelled like **Vicks' Nose Drops**” (J.Salinger, The Catcher in the Rye).

„ირგვლივ სულ წამლის შუშები და აბები ეყარა, და **სურდოს წვეთების** სუნი იდგა“ („irgvliv sul ts'amlis shushebi da abebi eqara, da **surdos ts'vetebis** suni idga“ - Translator V. Chelidze).

In this example the translator omitted the name of the pharmaceutical company – Vicks, which has no essential meaning for the given context.

Another strategy is to replace realia with different referents:

“It did not exactly beggar description, but it certainly had that word on the look-out for the **mendicancy squad**” (O'Henry, The Gift of the Magi).

„ოთახი მთლად მათხოვრული არ იყო, მაგრამ დიდი დიდი **მაწანწალათა გუნდის** საცხოვრებლად გამომდგარიყო“ („otakhi mtlad matkhovruli ar iqo, magram didi didi **mats'ants'alata gundis** satskhovreblad gamomdgariqo“ - Translator M. Natadze).

As we can see, the realia “mendicancy squad” (police forces who arrested homeless people and beggars) has been replaced by a different referent – „**mats'ants'alata gundi**” (a group of tramps).

While translating quasirealia (partially equivalent lexical units) translators tend to use either the strategies mentioned above or functional equivalents based on their skills and experience, the context and literary tradition.

An example of using a functional equivalent is:

“The Chief Courtier was joined by one after another of the other Courtiers, until at last there was a long chain of them, each holding the man in front of him by the waist, and a **tug-of-war** began between the Courtiers and the star” (P.L. Travers, Mary Poppins).

„კარისკაცთუხუცესს მეორე კარისკაცი მიეშველა, მეორეს _ მესამე, მესამეს _ მეოთხე და ასე შემდეგ და ასე შემდეგ გაიწეღნენ, თითქოს კარისკაცები **თაღგამს ჩაეჭიდნენ ამოსაღებად**“ („k'arisk'atstukhutsess meore k'arisk'atsi mieshveta, meores _ mesame, mesames _ meotkhe da ase shemdeg da ase shemdeg gaits'elnen, titkos k'arisk'atsebi **talgams chaech'idnen amosaghebado**“ - Translator L. Gogokhia). The referent “tug-of-war” denotes a competitive sport in which two opposing teams demonstrate their physical strength by pulling on opposite ends of a rope, each attempting to drag the other across a designated line. In the target text, the translator employs an allusion to the well-known fairy tale “The Enormous Turnip” as a functional equivalent of this referent. This cumulative tale recounts how a grandfather plants a turnip that grows so large that he is unable to uproot it alone. He subsequently enlists the assistance of the grandmother, granddaughter, and eventually several animals, until their collective effort finally succeeds in pulling the turnip from the ground. By drawing on this culturally familiar narrative, the translator replaces the original reference with one that is more readily accessible and comprehensible to young readers, while preserving the underlying concept of a coordinated pulling effort.

Conclusions

To summarize, when translating non-equivalent and partially equivalent lexical units, the translator is confronted with two fundamental challenges. On the one hand, the target text must remain fully comprehensible to the reader; on the other, it should preserve the national and cultural connotations embedded in the semantics of realia and quasi-realialia. To achieve this balance, Georgian translators employ a diverse range of strategies (transcription, calquing, generalization, descriptive translation, omission and cultural substitution) aimed at facilitating effective intercultural communication. The selection of a particular strategy is largely determined by the specific characteristics of the communicative context, including the target audience, the purpose of the translation and the degree of cultural distance between the source and target cultures.

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The Role of Teacher Autonomy in Classroom Management Methodology

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Abstract. This article examines the role of teacher autonomy in classroom management methodology, emphasizing its significance in fostering adaptive, responsive, and learner-centered educational environments. In contemporary pedagogy, classroom management extends beyond discipline to encompass instructional organization, emotional climate regulation and the facilitation of meaningful student engagement. Teacher autonomy is conceptualized as the professional capacity to make context-sensitive decisions regarding instructional strategies, behavioral expectations and classroom procedures. The article integrates theoretical analysis with practical examples from an English as a Foreign Language (EFL) classroom, illustrating how autonomous adaptations in lesson planning, task design and behavioral redirection contribute to improved classroom dynamics.

Classroom management has long been considered one of the most significant components of effective teaching. Traditionally associated with discipline, order, and control, the concept has gradually expanded to include the organization of learning environments, the development of positive classroom climate, and the promotion of student engagement. In contemporary pedagogy, classroom management is not merely a set of behavioral technological system that integrates instructional planning, communication strategies, emotional intelligence, and reflective practice. Within this framework, teacher autonomy emerges as a fundamental principle. Teacher autonomy refers to the degree of independence and decision-making power that educators have in their classrooms and professional practices. It encompasses the ability of teachers to make choices about their teaching methods, curriculum, and classroom management strategies without excessive interference from external authorities. This independence is crucial for fostering a positive learning environment and encouraging innovative practices that meet the diverse needs of students:

1. Teacher autonomy can lead to increased job satisfaction as educators feel more empowered in their roles.
2. Research indicates that greater teacher autonomy is associated with improved student engagement and academic performance.
3. Autonomy encourages teachers to adopt innovative instructional strategies tailored to their students' specific needs.
4. External factors such as standardized testing and rigid curriculum mandates can undermine teacher autonomy.
5. Supporting teacher autonomy often involves fostering a school culture that values trust, collaboration and professional growth.
 - How does teacher autonomy impact student learning outcomes in a classroom?

Teacher autonomy significantly impacts student learning outcomes by allowing educators to tailor their teaching methods of their students. When teachers have the freedom to experiment with different instructional approaches, they can engage students more effectively, leading to increased motivation and understanding. Research shows that classrooms led by autonomous teachers often see higher levels of student participation and academic achievement because these educators can adapt their lessons based on real-time feedback from their students.

- Discuss the challenges that can restrict teacher autonomy in educational settings

Several challenges can restrict teacher autonomy, including stringent standardized testing requirements, prescriptive curricula, and administrative oversight. These factors can limit educators' ability to make independent decisions about their teaching practices. Additionally, a lack of support from school administration or insufficient professional development opportunities can further hinder teachers' autonomy, creating an environment where they feel compelled to adhere strictly to external mandates rather than exercising their creative judgment in the classroom.

- Evaluate the role of school leadership in promoting or hindering teacher autonomy within an educational institution

Leadership plays a critical role in either promoting or hindering teacher autonomy. Effective leaders encourage a culture of trust and collaboration, allowing teachers the freedom to innovate and make decisions regarding their instructional practices. When school leaders prioritize professional development and provide resources for teachers to explore new methods, they empower educators to take ownership of their teaching. Conversely, if leadership imposes rigid controls or prioritizes compliance over creativity, it can stifle teacher autonomy, negatively impacting both teacher morale and student learning.

Modern classroom management is preventive rather than punitive. It focuses on creating conditions in which learning can flourish. Effective management includes:

- Establishing clear expectations
- Designing engaging tasks
- Maintaining structured routines
- Monitoring student behavior
- Encouraging positive relationships

However, the success of these components depends on the teacher's ability to interpret classroom situations. No two classes are identical. Student personalities, cultural backgrounds-motivational levels, and group dynamics vary significantly. Therefore, a standardized approach may produce inconsistent results.

Teacher autonomy enables educators to move beyond rigid behavioral systems. Instead of applying predetermined sanctions, autonomous teachers analyze underlying causes of behavior. They consider whether disruption results from boredom, confusion, social tension, or lack of challenge. Such diagnostic thinking transforms management into a reflective practice.

From a methodological standpoint, autonomy involves three interconnected dimensions:

1. Instructional Autonomy_ the ability to select and adapt teaching strategies. Instructional autonomy allows teachers to modify lesson plans in real time. For example, in a grammar lesson on conditional sentences, a teacher observes that students struggle with formulating complex structures. Instead of proceeding with advanced exercises, the teacher introduces a quick collaborative board game where students complete simpler "If I were...." prompts. This adjustment prevents frustration and maintains confidence. Or conversely, if students master the material quickly, the teacher may introduce spontaneous debate tasks using the target grammar. This prevents boredom- a common source of misbehavior.
2. Organizational Autonomy_ the capacity to design classroom procedures and routines. Strategic Seating Arrangement: If two students consistently distract each other, an autonomous teacher may rearrange seating-not as punishment, but as a preventive measure explained calmly and rationally. Flexible Group Work: During project-based learning, a teacher notices imbalance in participation.
3. Relational Autonomy_ the competence to manage interpersonal dynamics constructively. De-escalating Conflict: If a student reacts defensively after

correction, instead of public confrontation, the teacher may speak privately after class, preserving dignity while addressing behavior. For example, transforming disruption into responsibility. In an English storytelling activity, two students begin whispering. The teacher assigns them the role of “language monitors”, responsible for noting new vocabulary. This redefines their behavior constructively. Relational autonomy strengthens trust and respect, essential components of sustainable classroom management.

These dimensions interact within classroom management methodology. Without autonomy, management becomes mechanical; with autonomy, it becomes responsive and context-sensitive.

Teacher autonomy enables educators to move beyond rigid behavioral systems. Instead of applying predetermined sanctions, autonomous teachers analyze underlying causes of behavior. They consider whether disruption results from boredom, confusion, social tension, or lack of challenge. Such diagnostic thinking transforms management into a reflective practice.

Teacher autonomy also influences the psychological climate of the classroom. When teachers feel professionally empowered, they demonstrate greater confidence and emotional stability.

This emotional regulation directly affects students’ perceptions of authority and fairness.

There are some classroom scenarios:

Preventive engagement_ The teacher begins with a short humorous poll question: “Should school start later in the morning?” Students vote physically by moving to different corners of the room. This physical movement reduces restlessness, builds energy, encourages immediate participation. Teacher autonomy is visible in choosing kinesthetic engagement instead of starting with textbook exercises.

Controlled practice_ Students receive sentence starters to scaffold argument formation. However, several quieter students hesitate. Instead of forcing participation, the teacher introduces “Think-Pair-Share”. Students first write ideas privately, then discuss in pairs before speaking publicly. This methodological adjustment reduces anxiety and prevents disengagement.

Managing emerging conflict_ During debate, voices rise and interruptions occur. Rather than imposing silence abruptly, the teacher pauses the discussion and introduces a visual speaking token system—only the student holding a marker may speak. This simple autonomous intervention restores order without diminishing enthusiasm.

Reflective closure_ The teacher asks: “What helped you express your ideas clearly?” “What made the debate respectful?” Students identify turn-taking and preparation time as helpful. This reflection reinforces positive behavior patterns.

On balance, the teacher autonomy positively influences student motivation, emotional safety, participation equity, behavioral consistency, academic performance. In this case students perceive flexibility, also, the teacher autonomy strengthens classroom structure by aligning management strategies with students’ cognitive, emotional, and social needs. Furthermore, that autonomy supports teacher motivation and professional identity, thereby positively influencing classroom climate. The article concludes that cultivating teacher autonomy within teacher education programs is essential for sustainable classroom management practices and for promoting both academic achievement and cooperative learning environments.

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Sociological Sciences

The Impact of Measuring Academic Achievement

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Abstract: This paper examines the significance of the assessment process and the role of the assessor in education, as well as their contribution to the development of socially successful students. Assessment, teacher competence, the teacher's role as a psychologist, the identification of individual abilities, and student motivation during the assessment process are all determining factors in the formation of a student's personality. The effectiveness of assessment is also influenced by appropriate mechanisms, constructive feedback, and the professional knowledge of the teacher.

This study seeks to emphasize the importance of teachers' professional skills and their awareness of the impact that assessment may have on students. Particular attention is paid to the necessity of developing psychological competencies that enable teachers to understand students' individual needs and characteristics. Teachers should ensure the inclusion of all students in the learning process and support the identification and development of their individual strengths and abilities.

Keywords: assessment, progress, teacher, student, psychology.

Introduction: Assessment plays a crucial role in determining success in virtually every sphere of a person's activity. Although assessment methods vary across different fields, within the academic environment student assessment systems are generally established and regulated by educational authorities and state institutions.

Assessment constitutes one of the fundamental components of the teaching and learning process. Therefore, the instruments, mechanisms, and content of assessment must be carefully designed from the outset and aligned with the intended learning objectives and outcomes. Within this process, the teacher assumes the role of a guide and facilitator whose responsibility is to ensure objectivity in assessment. Unfair or inaccurate assessment may have long-term consequences for a student's identity formation and social positioning.

Assessment is an especially sensitive aspect of education as it inevitably assigns value to students' performance and abilities. Teacher competence, professional experience, and the involvement of educational psychologists are therefore of primary importance in preventing psychological frustration and negative developmental outcomes among students.

Assessment can serve as a powerful source of motivation; however, it can also significantly influence a student's self-esteem. Both underassessment and overassessment may lead to undesirable consequences. Excessively positive evaluations may cause students to develop unrealistic perceptions of their abilities and create expectations that cannot be fulfilled in practice. When students later encounter difficulties in achieving desired goals, they may experience considerable frustration due to the discrepancy between expectations and reality. Similarly, inflated assessments may foster the belief that success can be achieved with insufficient effort.

Consequently, assessment should not be viewed merely as the assignment of grades or scores. Rather, it is one of the key factors shaping personal development and social identity. Clearly

defined assessment criteria, combined with transparent communication of these criteria to students, are essential in preventing negative effects on self-perception and self-esteem.

In this regard, the teacher serves as the central figure guiding the assessment process. Their pedagogical expertise, professional knowledge, and personal qualities play a decisive role in ensuring that assessment contributes positively to student development rather than undermining it.

As noted in pedagogical literature, if a teacher evaluates a student unfairly and categorizes them among the less capable, they risk suppressing the student's sense of dignity and motivation to overcome challenges. Such judgments may negatively affect self-esteem and, in some cases, contribute to social maladjustment or the development of aggressive behavior as a means of self-assertion.

Particular attention should also be paid to the teachers' language while communicating with students. Teachers' words, expressions, and attitudes can significantly influence students' self-perceptions. The effectiveness of a teacher's influence is often determined by the richness, clarity, and emotional expressiveness of their communication, as well as by the quality of the relationships they establish with learners.

Main part: In order to define assessment and discuss its impact, it is first necessary to consider the role of educational psychology in this process and to clarify what educational psychology entails. Educational psychology is a branch of applied psychology that utilizes psychological theories and techniques to understand how individuals think and learn, as well as how educators can effectively address students' needs throughout the learning process. Psychology assists educators in analyzing various aspects of teaching and learning, including understanding what occurs during instruction, identifying students' difficulties, and designing lessons that are responsive to learners' individual needs.

It is equally important to define the teaching and learning process itself, as assessment is one of its fundamental components and plays a significant role in shaping individual development. Learning has been interpreted in various ways. Some psychologists, particularly behaviorists, view learning as a relatively permanent change in an individual's behavior. Others define learning as a change in the type and amount of knowledge individuals possess or in the way they perceive and interpret the world around them. The learning process demonstrates what individuals gain from experience and how these gains enable them to work and function more effectively. Therefore, learning may manifest itself through strategic changes, improved problem-solving abilities, or new ways of thinking about a particular issue.

In this context, individuals need assessment in order to understand the extent of their progress, engage in self-evaluation, and receive external feedback regarding the knowledge and skills they have acquired. The teacher plays a crucial role in developing these competencies. As highlighted in pedagogical literature, when applying assessment methods in education, teachers must take into account students' age-related and individual characteristics, as well as their initiative, determination, and self-control. Consequently, a teacher's ability to assess students accurately is of great importance. Effective assessment requires not only subject knowledge but also the capacity to identify students' personal characteristics and evaluate their academic performance fairly and objectively.

The concept of assessment has been defined in various ways within educational literature. Educational assessment generally refers to a set of methods and processes through which information about student learning is collected, analyzed, interpreted, and often quantified through grades or scores. Assessment is indispensable because, without it, it would be impossible to determine students' progress and identify areas requiring improvement. It enables educators to recognize learning needs and develop strategies to address them effectively.

As Boyle and Charles (2009) note, assessment is endemic to education and is often continuous, informal, frequent, and embedded in everyday classroom interactions. It encompasses an ongoing dialogue between teacher and student. Contemporary educational theory also emphasizes authentic assessment, which focuses on students' active participation in learning and prioritizes competencies such as critical thinking, creativity, problem-solving, and personalized learning experiences.

Within authentic assessment, teacher competence as an assessor becomes particularly important. The continuous development of assessment-related skills should be encouraged both at the individual and institutional levels. Several factors must be considered during the assessment process, including understanding students' expectations, determining whether their participation in learning aligns with those expectations, and identifying ways to enhance their engagement.

In many respects, the teacher assumes the role of a psychologist during assessment. Teachers design lessons, select appropriate activities, formulate questions, and employ assessment techniques that enable them to evaluate student progress while taking individual differences into consideration. Effective assessment requires attention to the psychological characteristics and personal circumstances of each learner. Furthermore, collaboration with educational psychologists can contribute significantly to understanding and addressing students' psychological needs.

Educational scholars have long argued that a teacher's knowledge and pedagogical mastery play a decisive role in personality development. Pedagogical expertise encompasses the ability to identify students' personal traits, dispositions, and abilities on an individual level. While discussions of teacher competence often focus primarily on subject-specific expertise, equal attention should be given to the teacher's psychological competencies and their influence on student development.

Another essential component of the assessment process is feedback. Students should be provided with opportunities to act upon feedback and improve their performance accordingly. In this regard, teacher's experience is critical in determining how feedback is communicated. Educators must be able to discuss achievements and areas requiring improvement in a manner that motivates students to address their weaknesses without undermining their self-esteem or discouraging further effort.

Informal assessment also plays a significant role in the learning process. Through observation of students' participation, engagement, and performance during classroom activities, teachers can draw conclusions regarding students' acquired knowledge, developed skills, and areas requiring further attention. Critical thinking, logical reasoning, creativity, and situational awareness are among the key competencies that enable teachers to conduct effective assessments.

Teacher competence becomes particularly evident during lesson planning. Educators must clearly define instructional objectives and determine the methods and criteria through which learning outcomes will be assessed. Teachers guide students toward educational goals through carefully designed instructional strategies while ensuring that learners understand the expected outcomes. The selection of appropriate assessment methods is therefore a crucial professional responsibility. Assessment should not diminish students' self-esteem; rather, it should encourage the recognition of challenges and foster motivation for improvement.

Assessment tools serve not only to measure student achievement but also to evaluate the effectiveness of teaching methods. The accuracy of assessment depends on the appropriate use of assessment mechanisms, careful analysis of data, and consideration of students' individual characteristics and learning needs.

Educational literature further emphasizes that talent and ability are individual characteristics upon which successful pedagogical practice largely depends. These qualities require continuous

development through interaction with the environment. Pedagogical competence, as an internal capacity, evolves and strengthens through professional experience and environmental influences. In an era characterized by rapid technological advancement and constant societal change, the development of teachers' knowledge, skills, and professional competencies has become increasingly important. Technological progress significantly influences students' personal development and may generate new forms of psychological pressure. Consequently, teachers must be prepared to address emerging challenges and support students in adapting to a rapidly changing environment.

In this context, teachers carry substantial responsibility. They must possess the ability to act not only as educators but also as informed practitioners who understand the psychological dimensions of learning and assessment. Through accurate evaluation, effective communication, and collaboration with educational psychologists, teachers can motivate students, encourage active participation in learning, and contribute positively to their academic, personal, and social development.

conclusion

The issue discussed in this paper is of considerable importance for both the development of students' personalities and their future success. Continuous professional development, specialized training, and increased awareness of teachers' roles and competencies can significantly enhance effective collaboration between teachers and students.

Professional workshops, ongoing training opportunities, and the development of psychological competencies can equip teachers with the skills necessary to identify students' difficulties accurately and conduct fair and meaningful assessments. Such professional growth contributes positively to students' personal development and overall well-being.

A well-designed assessment process enables students to recognize and focus on their individual strengths and abilities, helping them utilize these competencies effectively in both academic and social contexts. Assessment plays a vital role in shaping students' self-perception, influencing the formation of their identity and character. In turn, these individuals contribute to the development of society through their achievements, knowledge, and active participation in social life.

Ultimately, accurate assessment and healthy self-evaluation foster confidence, motivation, and personal responsibility. Students who develop a realistic understanding of their abilities are more likely to become active, successful, and socially responsible members of society, contributing positively to both their communities and the broader development of their country.

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Factors influencing on Teachers' Job Performance in Schools

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Abstract: The main purpose of this article is to examine the factors influencing teachers' job performance in schools. Job performance is defined through a lot of factors. One of them is organizational culture as it encourages employees to feel valued and motivated. Through the research we aim to demonstrate collaborative approach as an organizational characteristic contributes to better performance compared to formally structured schools. Collaborative approach encourages employees to feel valued, motivated, and committed to their work. The study was conducted using a quantitative research method through a standardized questionnaire. OCAI; (Organizational Culture Assessment Instrument). The survey results indicate that organizational characteristics based on strict bureaucratic procedures and formal structures receive the lowest level of support, whereas a family-like organizational environment is considered highly important by the majority of respondents.

Keywords: job performance, organizational culture, school climate, teachers, educational effectiveness, academic achievement

Introduction: In recent years, schools have faced increasing challenges related to improving teachers' job performance and overall educational effectiveness. Organizational culture plays a crucial role in shaping school operations, staff performance, and students' academic outcomes. When schools are well-organized and supportive, teachers can focus more effectively on teaching rather than administrative difficulties, unclear policies, or organizational inefficiencies. A positive school climate creates a stable learning environment where students can thrive academically and socially. Organizational culture influences communication, collaboration, motivation, and professional development among school staff.

Supportive approach within the school means clear communication, teamwork, fair policies, conflict resolution mechanisms, and employee motivation. Schools characterized by supporting cultures build trust among administrators, teachers, students, and parents. Such environments encourage accountability, improve performance, and support continuous school improvement. Furthermore, these factors contribute to increased job satisfaction and reduced teacher burnout. As a result, schools demonstrate higher levels of teacher performance and educational effectiveness.

Hypothesis: This study is based on the hypothesis that schools having high rate of collaborative approach are characterised by higher level of job performance.

Materials: The materials used in this study included academic books, peer-reviewed journal articles, educational reports, and other reliable sources related to organizational culture and teacher performance. Additional materials consisted of educational policy documents and statistical software used for data organization and analysis.

The study also drew upon findings from international large-scale educational assessments, including TIMSS (Trends in International Mathematics and Science Study) and PIRLS (Progress in International Reading Literacy Study). These assessments provide valuable information regarding student achievement and educational effectiveness across countries.

Furthermore, reports and datasets from TALIS (Teaching and Learning International Survey), conducted by the OECD, were reviewed. TALIS provides comprehensive information on teachers' working conditions, professional development, instructional practices, and school leadership. These sources supported the interpretation and contextualization of the study findings.

Methodology: This study applied a quantitative research design to examine the relationship between organization characteristics and teachers' job performance in Georgian schools.

Data were collected through a standardized questionnaire based on the Organizational Culture Assessment Instrument (OCAI), the Competing Values Framework (CVF), developed by Quinn and Cameron (2011), as the primary theoretical and analytical framework. According to the CVF, organizational culture can be categorized into four distinct types:

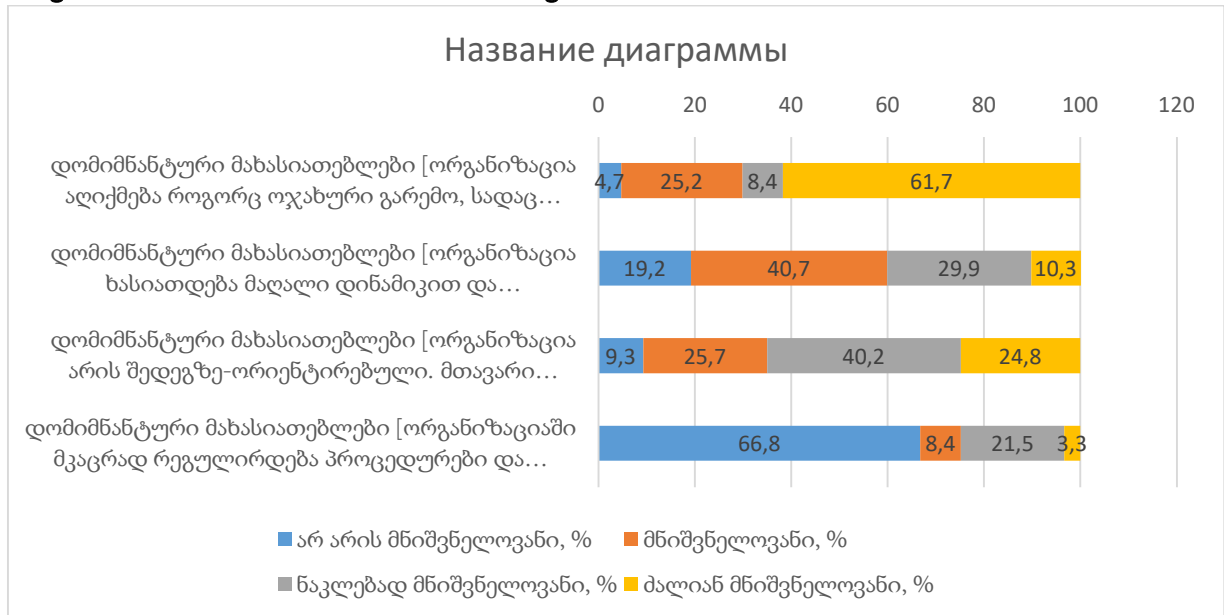
- **Clan Culture** – characterized by teamwork, participation, and employee commitment.
- **Adhocracy Culture** – characterized by innovation, creativity, and adaptability.
- **Market Culture** – characterized by competitiveness, productivity, and achievement of goals.
- **Hierarchy Culture** – characterized by formal structures, rules, and procedural control.

The questionnaire included questions designed to assess participants' perceptions of organizational culture and its characteristics. Using this instrument, the strength of each organizational culture type is determined by the total score assigned to a specific cultural category. Considering the respondents' characteristics and cultural differences, the scoring strategy was modified, and the statements were evaluated not by assigning numerical points, but by rating their level of importance. In the questionnaire, the dominance of a particular culture type is determined by the number of responses marked as "very important."

Face validity was conducted to assess the clarity and appropriateness of the items, and the content validity of each question was evaluated. The items were reviewed by educational and administrative leaders from various fields, as well as psychologists and teachers. The questionnaire was accompanied by a description of the study's relevance, aims, and theoretical framework of the items. Participants evaluated the extent to which the questions corresponded to the theoretical framework using an 11-point Likert-type scale. Data were collected, and based on the participants' feedback, the mean scores of each item's correspondence to the relevant research dimension were calculated. According to these results, ratings of 9, 10, and 11 were considered indicators of high validity. The population of the study consisted of teachers employed in public and private schools in Tbilisi, Georgia. The survey was distributed electronically using Google Forms. Data were analyzed using SPSS statistical software. Descriptive statistics, including frequency distributions and graphical representations, were used to identify dominant organizational culture types and examine their relationship with teachers' perceptions.

Results: The findings indicate that respondents generally prefer organizational environments characterized by collaboration, trust, and supportive relationships.

Diagram 1: Dominant characteristics of organization:



The least preferred organizational characteristic was a highly formalized environment based on strict procedures and bureaucratic control, where employee behavior is strongly regulated by formal rules and policies.

The majority of participants identified a family-like organizational environment as highly important. Respondents expressed strong support for organizational cultures that promote teamwork, open communication, mutual support, and participation in decision-making.

The results suggest that clan-oriented cultural characteristics are more positively perceived than hierarchical structures among teachers working in Georgian schools.

Discussion:

The findings support the assumption that organizational characteristic collaborative approach significantly influences teachers’ job performance and overall school effectiveness. Teachers appear to value collaborative and supportive environments more than highly bureaucratic organizational structures.

These results emphasize the importance of trust, communication, participation, and professional collaboration within educational institutions. Schools that foster positive relationships among staff members are more likely to create conditions that enhance teacher motivation, commitment, and productivity.

The preference for clan culture suggests that teachers perceive emotional support, teamwork, and shared values as essential components of a successful educational environment.

Conclusion: The study confirms that organizational characteristics and job performance are closely interconnected. They influence employees’ attitudes, behaviors, motivation, and commitment, which directly affect job performance.

The findings demonstrate that teachers strongly prefer supportive and collaborative organizational environments over rigid bureaucratic structures. Therefore, school leaders should prioritize the development of positive organizational cultures that encourage collaboration, professional growth, and employee well-being. Such efforts are likely to improve teacher performance, strengthen school effectiveness, and ultimately enhance student achievement.

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Psychological Sciences

Comparative analysis of the image of mother-woman in textbooks

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Keywords: mother, role model, educational system, sensitivity, emotional insight

Today, educational researchers have come to the conclusion that achieving the development and sustainability of student activity and independence, the importance of which has long been confirmed in education, will make a serious contribution to solving the problem we mentioned. Activity and independence are understood at this point, first of all, as the creativity, initiative of students, and their position as researchers in acquiring knowledge. The ways to implement this have been largely illuminated in methodological studies. Ensuring the activity and independence of students, especially in studying works of art, has always attracted attention. Although useful work has been done in this direction, there are still many tasks that need to be accomplished. Today, a more favorable opportunity has arisen for their solution. This is due to the emergence of technologies that allow approaching the educational process and its regularities from various aspects. It seems that it is impossible to solve the problem separately, in isolation. In the current conditions, where new educational approaches are emerging, there is a serious need for multidisciplinary research. It is important that contemporary research conducted in this context is directed towards identifying the conditions and means that allow for the reading of a literary text, its in-depth study, and the formation of a personal attitude to it. This goal sets as a primary task the step-by-step approach to innovation by referring to what has been achieved successfully. For example, in school practice, before reading, as well as after reading and mastering the content, students are asked questions in order to reveal the level of their independent approach to a literary work. More precisely, schoolchildren express their initial conclusions about the subject of the work, the essence of the ideas, stories, and events reflected in it, the cause-and-effect relationships between them, etc., and their attitude to all this.

In textbooks, the image of the mother is analyzed from psychological, didactic and social aspects as a symbol of unconditional love, sacrifice and moral values. This image plays an important moral support role in the formation of students as personalities, in the development of empathy skills and national-moral awareness.

In literature and language textbooks, the psychological analysis of the mother's image is mainly carried out in the following directions:

1. **Sacrifice and Unconditional Love-** The image of the mother is presented as a sacred being who endures all kinds of hardships for her children, putting her own desires and needs in the background. This presentation forms a deep sense of respect, love and gratitude towards parents (emotional intelligence) in children.
2. **Bearer of Moral Values -** As the protector of the family hearth, the mother is the first educator who instills in children moral qualities such as kindness, honesty, patriotism. Her psychological portrait lays the foundation for a sense of conscience and responsibility in children.

3. Emotional Support and Security - Psychologically, the image of the mother plays the role of a "secure base" for the child. The mother is the greatest psychological support for the child in the face of difficult life trials. Through the images of mothers in the works, the psychology of not giving up in the face of difficulties and being patient is instilled in students.
4. Development of Empathy - In literary works, feelings such as the concern, sadness, or pride that a mother feels for her child develop in students the ability to understand others and build empathy.

The function of the mother image in textbooks is not only to study the character of the literary hero, but also to create a healthy psychological and moral worldview in the reader (student).

The content of S. Rustam's work "Mother and the Postman" allows us to divide it into four parts, conditionally. First of all, the inner meaning of the episode 1 (description of the anxiety and worry of a mother waiting for a letter from her son), which is intended as the first part, should be clarified. Its successful solution depends on how the image of the mother is understood. The endless anxiety and tense psychological state of the mother, who is impatiently waiting for news from her son, whom she sent to the front, are presented with great skill. The mother, who has not received a letter from her son at the front for four months, has exhausted her patience. The mother, who receives news of her son from each front, is consumed by anxiety and doubt. The mother, who is filled with questions, believes that her son is not ill and has not died. However, she cannot explain the reason for his not writing a letter.

The mother, whose absent-minded gaze recalls the "cloudy sky" and whose tears recall the "first spring rain", gets up from her bed "at the crack of dawn" and waits for news from her son all day long. Clarifying these aspects makes it easier to determine the inner meaning (subtextual meaning) of that part. It can be expressed as follows: "A child is dearer to a mother than her own soul!". So what should the performer draw the listener's attention to when reciting that husa? In other words, what is the task (performance task) set before the performer?

It is appropriate to define the performance task in the following context: "To convey to the listeners the greatness of a mother's love for her son and her endless concern."

Conclusion: One of the foundations for analyzing women's poetry—an undeniably specific foundation—can be the theme of motherhood. A man can create the image of a mother, but never the image of motherhood. This is the point that divides and will never reconcile man and woman. The foundation of the image's persistence lies in its origins in archaic representations and its retransmission, unchanged, through cultural or cultural-religious idealization, into new literary traditions. The term "real mother" is applicable to contemporary women's poetry, as the image of motherhood and motherhood is becoming more concrete, revealing the mother's personality and inner world, something not present in the folkloric tradition. This phenomenon is entirely natural: culture changes, literary eras pass—traditions change, and consequently, new variations in images of motherhood emerge. Yet, at the same time, the archaic understanding of woman as mother remains. The undervaluation of motherhood, which dates back to ancient times, also persists, since the highest meaning of a woman's life—to give birth—is understood, in light of feminist theories, as a simplified biological purpose for women, a reduction of their social roles.

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Economic Self-Efficacy and Economic Socialization: The Role of Psychological Resources in Shaping Economic Behavior

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Keywords: Economic Self-efficacy, Economic Socialization, Economic Behavior, Financial literacy, Financial Skills, Financial Independence, Self-efficacy.

The purpose of this study is to study the relationship between economic self-efficacy and economic socialization and to determine the role of economic self-efficacy in the process of forming economic behavior. Economic self-efficacy is considered as an individual's belief in his or her own abilities in the context of successfully completing financial and economic tasks, and economic socialization is considered as a process through which a person acquires economic knowledge, values, skills and behavioral models.

The empirical research data were processed in the program - SPSS. 528 respondents participated in the study. Descriptive statistics and Pearson correlation analysis were used for data analysis. The results showed that 45.6% of the respondents are characterized by a high level of economic self-efficacy, 45.5% - medium, and 8.9% - low. Correlation analysis revealed significant positive relationships between economic self-efficacy and financial independence ($r = .635, p < .001$), values ($r = .653, p < .001$), psychological flexibility ($r = .626, p < .001$), financial knowledge ($r = .552, p < .001$), financial skills ($r = .492, p < .001$), and general self-efficacy ($r = .532, p < .001$).

The results confirm that economic self-efficacy is one of the most important psychological mechanisms of economic socialization and has a significant impact on the formation of economic behavior. High economic self-efficacy is associated with financial activity, independent decision-making, effective management of financial resources, and economic independence. The results of the study emphasize the importance of developing economic self-efficacy in financial education and economic socialization programs as one of the key prerequisites for economic well-being and successful economic functioning.

Introduction

In the modern world, economic success and financial well-being do not depend only on material resources. More and more research confirms that psychological factors, including self-efficacy, motivation, locus of control and value orientations, significantly influence an individual's economic behavior. In this context, economic self-efficacy is of particular importance, which is considered as an individual's belief in his or her own abilities to successfully perform economic and financial tasks (Bandura, 1997).

Economic behavior is the decisions and actions taken by an individual in the economic environment related to the acquisition, distribution, consumption, saving and provision of financial well-being of resources. According to modern approaches, economic behavior is not only the result of rational choices; It is formed by the influence of psychological, social and cultural factors and reflects a person's financial knowledge, skills, values, motivation and responsibility (Katona, 1975; Webley & Nyhus, 2006).

The basis for the formation of economic behavior is economic socialization - the process through which an individual acquires economic knowledge, values, norms and behavioral patterns. As a result of economic socialization, a person learns to manage financial resources, take economic

responsibility and adapt to the demands of the economic environment (Gudmunson & Danes, 2011).

Economic self-efficacy is considered one of the most important products of economic socialization, because it determines how confident an individual is in his or her own abilities in solving economic problems and making financial decisions.

Theoretical foundations of economic self-efficacy

The concept of self-efficacy was first formulated by Bandura within the framework of social cognitive theory. According to the author, self-efficacy refers to a person's belief that he can successfully perform specific actions and achieve desired results (Bandura, 1997).

In the economic sphere, self-efficacy reflects a person's confidence in his own financial capabilities. People with high economic self-efficacy are more inclined to make independent decisions, actively manage financial resources and better cope with economic difficulties. Conversely, low economic self-efficacy is often associated with avoidance of financial responsibility, a sense of uncertainty and a passive attitude towards economic challenges.

Economic self-efficacy has a significant impact on both financial behavior and professional development and the achievement of economic independence. Accordingly, it is considered one of the main psychological mechanisms of economic socialization.

Research Results

The research assessed the level of economic self-efficacy of respondents. According to the results obtained, the majority of respondents are characterized by medium or high economic self-efficacy.

High economic self-efficacy was revealed in 45.6% of respondents, medium level – in 45.5%, and low level – in only 8.9%.

The data obtained indicate that the majority of respondents have a positive perception of their own economic capabilities and sufficient psychological resources to overcome financial challenges.

The group with medium economic self-efficacy, which is most widely represented in the study, can be considered a category at the development stage. Representatives of this group already have some economic knowledge and experience, although the influence of the social environment and educational processes is still important for them. Accordingly, financial education programs and practical economic experience can be especially effective for representatives of this category.

Respondents with high economic self-efficacy are likely to exhibit more economic independence, financial responsibility, and long-term planning-oriented behavior. They make financial decisions more confidently and are better able to manage financial resources.

A relatively small group of respondents (8.9%) with low economic self-efficacy requires special attention. These individuals may be characterized by difficulty in making financial decisions, less confidence in their own abilities, and a tendency to shift economic responsibility to external factors.

Economic self-efficacy and economic socialization

In the process of economic socialization, a person gradually acquires the knowledge and skills necessary for successful functioning in the economic environment. However, the presence of economic knowledge does not always lead to effective economic behavior. For this, it is necessary for the individual to have faith in his own abilities and a willingness to apply the acquired knowledge in practice.

The results of the study showed that economic self-efficacy is significantly and positively related to almost all major components of economic socialization.

Specifically, economic self-efficacy is strongly correlated with values ($r = .653$, $p < .001$), financial independence ($r = .635$, $p < .001$), psychological flexibility ($r = .626$, $p < .001$), locus of

control ($r = .596, p < .001$), financial knowledge ($r = .552, p < .001$), self-efficacy ($r = .532, p < .001$), and financial skills ($r = .492, p < .001$).

These results indicate that economic self-efficacy is not an isolated characteristic. It is associated with both cognitive components (knowledge, skills), as well as personal and value factors. This once again confirms that economic behavior is the result of a complex social and psychological process.

The influence of economic self-efficacy on economic behavior

Economic self-efficacy has a significant impact on an individual's daily economic behavior. People with high self-efficacy are more involved in making financial decisions, more often carry out financial planning and are responsible for economic obligations.

A high level of economic self-efficacy is associated with:

Financial activity;

Independent economic decision-making;

Effective management of financial resources;

Professional motivation;

Effective solution of financial problems;

Setting and implementing long-term financial goals.

On the other hand, low economic self-efficacy may be associated with avoidance of financial responsibility, uncertainty in decision-making, and a passive attitude towards economic challenges.

Thus, economic self-efficacy is the psychological mechanism through which economic knowledge and experience are transformed into actual economic behavior.

Conclusion

The results of the study show that economic self-efficacy is one of the most important components of economic socialization. The majority of respondents are characterized by medium or high economic self-efficacy, which indicates their readiness to function successfully in the modern economic environment.

Correlation analysis showed that economic self-efficacy is closely related to financial knowledge, financial skills, financial independence, psychological flexibility, values, and self-efficacy. These results confirm that the formation of economic behavior depends not only on economic resources, but also on the psychological capabilities and social experience of the individual.

Accordingly, economic socialization programs and financial education initiatives should be focused not only on the transfer of economic knowledge, but also on the development of economic self-efficacy, since it is precisely the belief in one's own abilities that determines the active, responsible, and independent economic behavior of an individual.

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Legal Sciences

Legal issues of the mining industry's evolution in modern world

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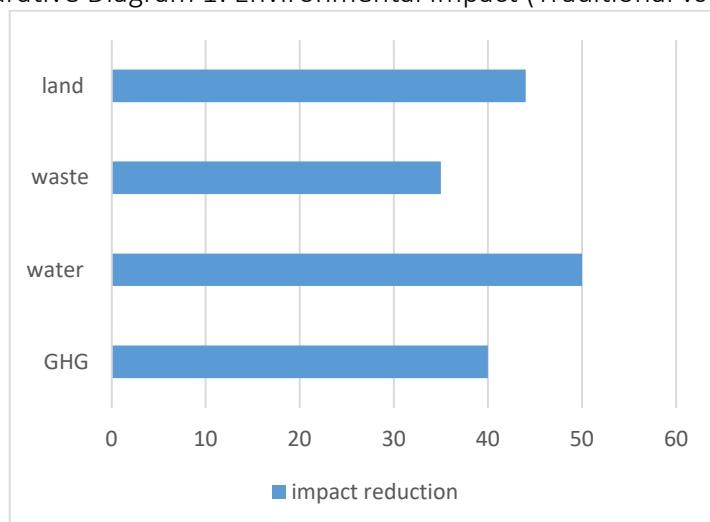
Keywords: industry, legal issue, sustainability, mining, climate change

The mining industry's evolution in the framework of the global shift to a green economy is a multicolored and multifaceted process that brings together economic need and environmental concern. This thesis has shown that the mining industry is a keystone to making renewable energy technologies possible, as it provides essential raw materials like lithium, cobalt, nickel, and rare earth elements. Meanwhile, mining is one of the major causes of environmental degradation, posing an essential conflict between economic growth and sustainability.

The historical discussion of the mining industry verifies that the industry has developed to be less traditional mining of resources and more technologically focused and strategic. The demand for critical minerals, in turn, grew significantly in the modern age because of the growth of renewable energy systems. This change underscores the increasing role of mining in meeting the global climate goals and the necessity to pursue more sustainable mining.

But the study has demonstrated that there is two-sidedness in the mining industry. On the one hand, it promotes economic growth and technological progress, as well as green energy transition. Conversely, it is a source of environmental issues like greenhouse gases, water pollution, land degradation, and biodiversity. Such duality requires coming up with efficient legal, regulatory and technological solutions.

Comparative Diagram 1: Environmental Impact (Traditional vs Sustainable Mining)



The data show that sustainable mining practices can decrease environmental footprint by 35%-50%, and the greatest change was in the reduction of water pollution.

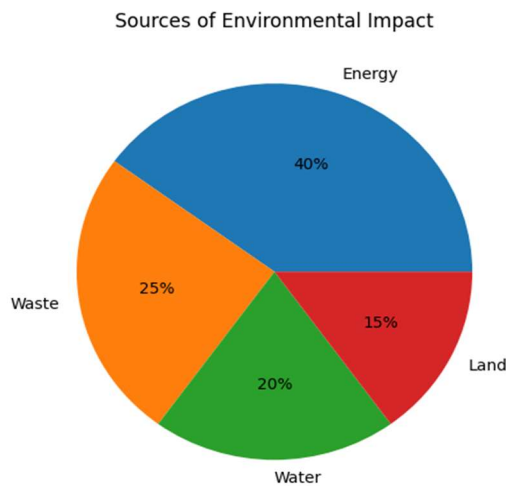
The discussion of the law and regulatory systems in this thesis has pointed out how they are key in regulating the effects on the environment. The national legal systems provide a framework

on how to regulate the mining activities through licensing, environmental impact assessment, and compliance provisions. Meanwhile, the policies of a country are shaped by international regimes, like the Paris Agreement, which encourages sustainable practices and the reduction of emissions.

Moreover, the incorporation of international standards like ISO 14064-1:2018 gives viable instruments to quantify and control the effects on the environment, especially greenhouse gases. These standards promote the use of environmental regulations and transparency.

Moreover, the discussion of sustainable mining has shown that the implementation of technology and effective management of resources are critical factors to minimize environmental impacts. Use of renewable energy, water recycling, and state-of-the-art waste management technologies greatly boost the environmental performance.

Comparative Diagram 2: Sources of Environmental Impact in Mining



The biggest environmental impact (40%), however, is energy consumption, which underlines the need to switch to renewable energy in the mining process.

The results also highlight the significance of policy and strategic approaches to sustainable mining. Governments need to enhance the legal frameworks, the enforcement mechanisms and facilitate the use of international standards. Meanwhile, mining companies need to apply environmental, social, and governance (ESG) in their processes.

Conclusion

Finally, the mining sector is an essential part of the green economy development, yet its sustainability requires effective combination of legal, technological, and policy decisions. The comparative analysis in this section shows that much can be done to change the situation by applying sustainable mining practices and enhancing regulatory frameworks.

Findings of this study support the premise that although mining will remain an important aspect of world development, it has to be anchored in a sustainable strategy that emphasizes the need to protect the environment, manage resources and be socially responsible. This equilibrium is vital in making sure that the mining sector plays a positive role in globalizing to a sustainable and low-carbon future.

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Chemical Sciences

ШҰЖЫҚ ӨНІМДЕРІН ӨНДІРУДЕГІ ШИКІЗАТ ПЕН ҚОСПАЛАРДЫҢ ФУНКЦИОНАЛДЫҚ РӨЛІ

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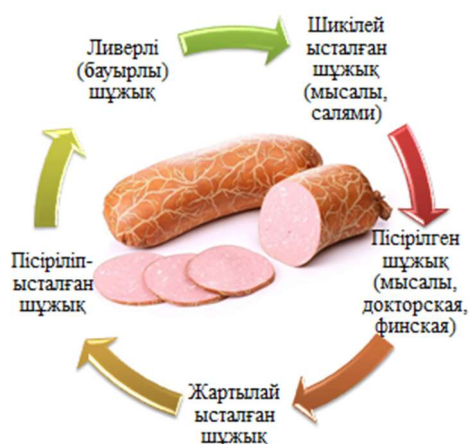
Кіріспе

Қазіргі кезеңде шұжық өнімдері халықтың тамақтану құрылымында маңызды орын алып отыр. Урбанизация үдерісінің күшеюі, өмір ырғағының жеделдеуі және уақыт үнемдеуге бағытталған тамақ өнімдеріне деген қажеттіліктің артуы бұл өнім түрінің тұтыну көлемін ұлғайтты. Құрамы жағынан дайын әрі өңделген тағам ретінде шұжық өнімдері қолжетімділігімен, сақтау мерзімінің салыстырмалы ұзақтығымен және ассортиментінің кеңдігімен ерекшеленеді. Осы факторлар шұжық өнімдерінің қазіргі қоғамда кеңінен тұтынылуына ықпал етуде.

Шұжық – еттен немесе ет өнімдерінен арнайы технологиялық өңдеу арқылы дайындалатын жоғары тағамдық құндылығы бар өнім. Бұл өнім адамдардың тамақтану рационасында ерекше орын алады, себебі құрамында жоғары сапалы ақуыз, май, дәрумендер мен минералды заттар бар.

Шұжық өнімдерін өндіруде қолданылатын шикізат пен қоспалар дайын өнімнің сапасын, дәмін және тағамдық құндылығын айқындайды. Сол себепті өндіріске енгізілетін әрбір құрамдас бөлік технологиялық тұрғыдан негізделіп таңдалады. Шұжық өнімдері бірнеше белгілері бойынша жіктеледі:

Өңдеу түріне қарай



2. *Шикізат түріне қарай*: еттен (сиыр, шошқа, қой, тауық), ет және сүбөнімдерден, өсімдік қоспалары бар (соя, крахмал қосылған), диеталық және балаларға арналған түрлері.

Қолданылатын тағамдық қоспалар мен олардың рөлі. Шұжық өндірісінде тек ет емес, әртүрлі қоспалар мен дәмдеуіштер де маңызды рөл атқарады.

Қоспалар өнімнің технологиялық және органолептикалық қасиеттерін жақсартады:

- *Фосфаттар* - ақуыздың ісіну қабілетін арттырып, өнімнің құрылымын нығайтады.
- *Аскорбин қышқылы (С витамині)* - түс түзілу процесін тездетеді және антиоксидант қызметін атқарады.
- *Дәмдеуіштер мен шөптер* (қара бұрыш, мускат жаңғағы, сарымсақ, кориандр) дәм мен иіс береді.
- *Соя* протеиндері мен крахмал өнімнің консистенциясын біркелкі етеді. Стабилизаторлар және эмульгаторлар судың бөлініп кетуін болдырмайды.

Шикізат пен қоспалардың өнім сапасына әсері. Шұжық өндірісінде шикізат пен қоспалардың арақатынасы өте маңызды. Егер ет сапасы төмен болса немесе қоспалар мөлшері дұрыс сақталмаса, өнімнің дәмі, иісі және құрылымы нашарлайды. Мысалы: нитрит тұзы артық болса, ащы дәм пайда болады. Фосфат аз болса өнім құрғақ әрі үгітіліп кетеді. Май аз болса шұжықтың шырындылығы төмендейді. Сондықтан өндіріс барысында шикізат сапасын бақылау, дозалау дәлдігі, және технологиялық температура режимі қатаң сақталуы қажет.

Шұжық өндірісінің негізгі кезеңдері:



Шұжық сапасын анықтау көрсеткіштері. Шұжықның сапасы органолептикалық, физика-химиялық және микробиологиялық көрсеткіштер бойынша анықталады. Органолептикалық: түсі, иісі, дәмі, құрылымы, кесінді беті. Физика-химиялық: ылғалдылық, тұз мөлшері, май мен ақуыз арақатынасы, рН деңгейі. Микробиологиялық: мезофильді бактериялар саны, ішек таяқшалары тобының бактериялары, зең мен ашытқының болуы.

Шұжық сақтау шарттары мен жарамдылық мерзімі. Шұжықтың сапасы мен қауіпсіздігі сақтау температурасына байланысты:



Пісірілген колбаса:
+2...+6°C, 5–7 тәулік



Жартылай ысталған:
+0...+8°C, 10–20
тәулік



Шикілей ысталған:
+10...+15°C, 1–2
айға дейін

1-сурет. Шұжық өнімінің сақтау мерзімі

Ылғалдылық 75–80% аралығында болуы керек. Сақтау кезінде өнімді орау материалдары (вакуум, полимер қаптар) сапаны ұзақ сақтауға мүмкіндік береді.

Қазақстандағы шұжық өндірісінің қазіргі жағдайы. Қазіргі таңда Қазақстанда ондаған ірі және орта кәсіпорындар шұжық өнімдерін шығарады. Олардың ішінде: «Беккер и К», «Мясной стандарт», «БИЖАН», «Орда Эт», «Сейфуллин өнімдері» сияқты компаниялар бар. Соңғы жылдары тұтынушылар табиғи, экологиялық таза және қоспасыз өнімдерге көбірек мән беруде. Сол себепті өндірушілер шұжықты өсімдік талшықтары мен функционалды ингредиенттермен байыту жолдарын іздеуде.

Шұжық өндірісінде шикізат пен әртүрлі тағамдық қоспалардың сапасы дайын өнімнің дәміне, иісіне, түсіне және құрылымына тікелей әсер етеді.

Қазіргі уақытта шұжық өнімдері күнделікті тұрмыста кеңінен қолданылып отыр, өйткені оларды сақтау, тасымалдау және тұтыну тұрғысынан қолайлылығы жоғары. Бүгінгі таңда отандық нарықта түрлі өндірушілердің өнімдері кең таралған. Өнім ассортиментінің молдығы мен дәмдік қасиеттерінің алуан түрлілігі тұтынушыларға кең таңдау жасауға мүмкіндік береді. Осы сан алуан өнімдердің ішінде «Орда» және «Финский» шұжықтары ерекше сұранысқа ие. Аталған шұжық түрлері өзара құрамы мен сапалық көрсеткіштері бойынша айырмашылықтарға ие.

<i>Көрсеткіш</i>	<i>Орда</i>	<i>Финский</i>
Ет %	Сиыр еті жоғары үлесте, табиғилық деңгейі жоғары	Сиыр және тауық еті аралас, жалпы ет мөлшері орташа
Майлылық деңгейі	Майлылық деңгейі Тұрақты, қалыпты майлылық	Майлылығы сәл жоғары болуы мүмкін, шырындылық көп
Қоспалар мөлшері	Фосфат, крахмал аз мөлшерде	Қоспалар көбірек (крахмал, фосфат, талшық)
Дәм	Классикалық, табиғи дәм	Хош иісі айқын, дәмдеуіштер көбірек
Сақталу мерзімі	Консерванттар аз → сақтау мерзімі орташа	Консерванттар, тұрақтандырғыштар көп → ұзақ сақталады

Тұз мөлшерін анықтау

Тұз мөлшерін анықтау кезінде өнім құрамында тағамдық тұздың (NaCl) нормадан артық немесе кем еместігі тексерілді. Бұл көрсеткіш шұжықтың дәміне, сақтау тұрақтылығына және микробиологиялық қауіпсіздігіне тікелей әсер ететіні анықталды. Колбасаның белгілі массасы (2-3г) өлшеніп, ыстық суда ерітіледі. Ерітіндіні сүзгіден өткізіп, күміс нитраты және калий хроматымен титрленеді.



Сары түсті тұнба түзілуімен титрлеу аяқталады. Нәтижесінде тұз мөлшері : "Финский -2,8%", "Орда - 2,3%". Өнім тағамдық тұрғыдан қауіпсіз және тұз мөлшері қалыпты деңгейде.



Сурет 1. Тұз мөлшерін анықтау

Крахмалдың бар жоғын анықтау

Крахмалдың бар-жоғын анықтау барысында йод ерітіндісімен реакция жүргізілді. Үлгінің көк түске боялуы крахмалдың бар екенін көрсетті. Бұл әдіс шұжық құрамына қосылатын өсімдік тектес қоспаларды анықтауға мүмкіндік береді.

Шұжық үлгісінен аз мөлшерде алынған сынамаға бірнеше тамшы йод ерітіндісін қосамыз. "Финский шұжығы" - сарғыш (крахмал аз) түске боялды. "Орда шұжығы" - қоңыр (крахмал бар) түске боялды. Шұжыққа бояғыш немесе көлем ұлғайтқыш ретінде крахмал қосылған.



Сурет 2. Крахмалды анықтау.

Қанттың бар-жоғын анықтау

Қанттың бар-жоғын анықтау үшін Бенедикт ерітіндісі қолданылды. Алдымен, колбасаны кіші бөлшектерге кесіп, суға ерітеміз (1:5 қатынасында). 2-3мл ерітіндіге 2мл йод ерітіндісін қосамыз. Қоспаны 2-3 минут қайнатамыз. Ерітінді көкшіл түстен қызыл-қоңыр түске өзгерсе, редукциялайтын қант кездеседі. Нәтижесінде: Финский шұжығы-әлсіз түс (қант аз), Орда шұжығы-қызылт тұнба (қант бар). Ерітіндінің қызғылт немесе қызыл түске айналуы өнімде редукциялаушы қанттардың бар екенін дәлелдеді.



Сурет 3. Шұжықтардың құрамындағы қантты анықтау

Майдың тотығу дәрежесін анықтау

Майдың тотығу дәрежесін анықтау кезінде май құрамындағы пероксидтік қосылыстардың деңгейі тексерілді. Ол үшін майын бөлек бөліп алып, калий йодидін қостық. Финский шұжығы- ақ түс (тотығуы төмен) сақтау сапасы қалыпты, Орда шұжығы-сарғыш (май тотығуға ұшыраған) тотығу белгісі бар. Тотығу дәрежесі жоғары болған жағдайда өнімнің дәмі, иісі және сақтау мерзімі нашарлайтыны анықталды.



Сурет 4. Майдың тотығу дәрежесін анықтау барысы

Жалпы зерттеу нәтижелері бойынша колбаса сапасын бағалау кезінде оның химиялық құрамын, физика-химиялық қасиеттерін және қосымша заттардың болуын анықтау маңызды екені дәлелденді. Бұл көрсеткіштер өнімнің тағамдық құндылығын, балғындығын және қауіпсіздігін қамтамасыз етуге мүмкіндік береді.

Қорытынды

Шұжық өнімдері – халық арасында кеңінен тұтынылатын, жоғары тағамдық және энергетикалық құндылығы бар өнім. Оларды өндіру технологиясы ғылым мен тәжірибенің дамуы нәтижесінде жетілдіріліп отыр.

Дегенмен, қазіргі таңда сапасыз немесе артық қоспалар қосылған өнімдер де кездеседі. Сондықтан тұтынушы өнім таңдау кезінде құрамын, сақтау шарттарын және өндіруші беделін ескергені жөн.

Болашақта отандық шұжық өндірісін дамыту, табиғи шикізат пайдалану және халықаралық сапа стандарттарына сай өндіру – еліміздің азық-түлік қауіпсіздігін қамтамасыз етудің маңызды бөлігі. Қорыта келгенде, шұжық өндірісіндегі шикізат пен тағамдық қоспалардың сапасы дайын өнімнің сапалық көрсеткіштеріне тікелей әсер етеді.

«Орда» және «Финский» шұжықтарының салыстырмалы талдауы олардың құрамдық айырмашылықтарын айқын көрсетті: Біріншісі - дәстүрлі, тығыз және қою дәмді болса, Екіншісі - заманауи қоспалармен дайындалған, жұмсақ әрі хош иісті өнім. Сондықтан шұжық өндірушілері шикізат таңдауда және қоспалар қолдануда ғылыми негізделген тәсілдерді ұстануы қажет. Бұл өнім сапасын арттырып, тұтынушылар сұранысын қанағаттандыруға мүмкіндік береді.

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Medical Sciences

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ПАТИЕНТ TRUST КАК ФАКТОР УСТОЙЧИВОСТИ ЧАСТНОЙ МЕДИЦИНСКОЙ ОРГАНИЗАЦИИ

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Аннотация

В современных условиях развития системы здравоохранения доверие пациентов становится одним из ключевых нематериальных активов медицинской организации. Рост конкуренции на рынке медицинских услуг, цифровизация здравоохранения, повышение информированности населения и развитие пациент-ориентированной модели оказания медицинской помощи обуславливают необходимость включения показателей доверия пациентов в систему стратегического и антикризисного управления медицинской организацией. Цель исследования – определить роль patient trust как фактора устойчивости частной медицинской организации и разработать подходы к его оценке в системе антикризисного управления.

Материалы и методы. Исследование выполнено на основе анализа деятельности многопрофильной частной медицинской организации ТОО «Clinic Miras». Используются методы системного анализа, сравнительного анализа, анализа научной литературы, оценки показателей удовлетворенности пациентов, Net Promoter Score (NPS), Customer Satisfaction Index (CSI), структуры обращений и жалоб пациентов.

Результаты. Установлено, что уровень доверия пациентов оказывает непосредственное влияние на устойчивость медицинской организации через показатели повторных обращений, лояльности пациентов, репутационной устойчивости и финансовой стабильности. Выявлено, что снижение доверия пациентов сопровождается ростом жалоб, уменьшением доли повторных визитов и снижением эффективности антикризисного управления. Предложена система оценки patient trust, включающая показатели NPS, CSI, индекс повторных обращений, структуру жалоб и цифровую репутацию медицинской организации.

Заключение. Доверие пациентов следует рассматривать как самостоятельный стратегический ресурс и один из ключевых факторов организационной устойчивости медицинской организации. Включение показателей patient trust в систему антикризисного управления позволяет повысить качество управленческих решений и обеспечить долгосрочную устойчивость медицинской организации.

Ключевые слова: patient trust, доверие пациентов, медицинская организация, антикризисное управление, устойчивость организации, NPS, CSI, репутационный менеджмент.

Введение

Современное здравоохранение переживает период существенных трансформаций, связанных с цифровизацией медицинской помощи, ростом конкуренции между медицинскими организациями, изменением ожиданий пациентов и повышением требований к качеству медицинских услуг. В данных условиях важнейшим фактором конкурентоспособности и устойчивости медицинской организации становится доверие пациентов.

Согласно данным Всемирной организации здравоохранения, доверие является одним из базовых элементов эффективного функционирования системы здравоохранения и оказывает влияние на приверженность лечению, удовлетворенность пациентов и результаты медицинской помощи. Высокий уровень доверия способствует формированию долгосрочных отношений между пациентом и медицинской организацией, тогда как его снижение приводит к ухудшению репутации, уменьшению пациентопотока и росту организационных рисков.

В последние годы понятие patient trust рассматривается не только как социально-психологическая категория, но и как управленческий показатель, отражающий устойчивость медицинской организации. Исследования Thom D., Hall M., Blendon R., Mechanic D., Gilson L., Ozawa S. и других авторов показывают, что доверие пациентов связано с качеством коммуникации, безопасностью медицинской помощи, прозрачностью деятельности организации и эффективностью системы управления качеством.

Для частных медицинских организаций Республики Казахстан данная проблема имеет особую актуальность. Развитие рынка медицинских услуг сопровождается усилением конкуренции, ростом значения цифровой репутации и расширением возможностей пациентов по сравнению с качеством медицинской помощи. В этих условиях показатели доверия пациентов становятся важным индикатором организационной устойчивости и требуют включения в систему антикризисного управления.

Несмотря на значительное количество исследований, посвященных удовлетворенности пациентов и качеству медицинской помощи, вопросы интеграции показателей patient trust в систему антикризисного управления медицинской организацией остаются недостаточно изученными, что определяет актуальность настоящего исследования.

Научная новизна исследования заключается в разработке интегрированной системы оценки patient trust как фактора устойчивости частной медицинской организации, включающей показатели лояльности пациентов (NPS), удовлетворенности пациентов (CSI), повторных обращений, структуры жалоб и цифровой репутации, объединенных в единый контур антикризисного управления.

Цель исследования

Определить роль patient trust как фактора устойчивости частной медицинской организации и разработать подход к оценке доверия пациентов в системе антикризисного управления.

Материалы и методы

Исследование выполнено на базе многопрофильной медицинской организации ТОО «Clinic Miras».

Методологическую основу исследования составили:

- системный анализ;
- сравнительный анализ;
- анализ научной литературы;
- анализ показателей удовлетворенности пациентов;
- анализ структуры жалоб пациентов;
- оценка показателей NPS и CSI;
- методы описательной статистики.

Для оценки уровня доверия пациентов использовались следующие показатели:

1. Net Promoter Score (NPS);
2. Customer Satisfaction Index (CSI);
3. доля повторных обращений пациентов;
4. количество жалоб на 1000 посещений;
5. рейтинг медицинской организации на цифровых платформах;
6. индекс репутационной устойчивости.

В качестве критериев оценки устойчивости использовались показатели сохранения пациентопотока, повторных обращений и репутационной стабильности организации.

Результаты и обсуждение

Оценка показателей доверия пациентов

Для комплексной оценки patient trust была разработана система мониторинга, включающая пять ключевых групп показателей:

NPS;

CSI;

Повторные обращения пациентов;

Жалобы пациентов;

Репутационный рейтинг.

Показатели представлены в таблице 1.

Таблица 1 — Ключевые показатели диагностики доверия пациентов

Направление	KPI	Управленческое значение
Лояльность	NPS	готовность пациента рекомендовать клинику и возвращаться
Удовлетворенность	CSI	оценка качества сервиса и пациентского опыта
Жалобы	количество и структура	ранние сигналы дефектов качества, доступности и коммуникации
Репутация	рейтинг в 2GIS/Google/Yandex	публичное восприятие клиники и цифровой репутационный капитал
Возврат	доля повторных пациентов	удержание пациентов и устойчивость отношений с клиникой
<p><i>Примечание: составлено автором на основе концепции Patient Trust Management, модели Patient Experience Framework (Picker Institute), рекомендаций Agency for Healthcare Research and Quality (AHRQ), исследований Berry L., Parasuraman A., Zeithaml V., Reichheld F., Doyle C., Safran D. по доверию пациентов, patient-centered care, качеству взаимодействия и репутационной устойчивости медицинских организаций</i></p>		

Анализ NPS

Одним из наиболее распространенных инструментов оценки лояльности пациентов является Net Promoter Score (NPS).

Расчет показателя выполнялся по формуле:

NPS = % промоутеров – % критиков (рисунок 1)

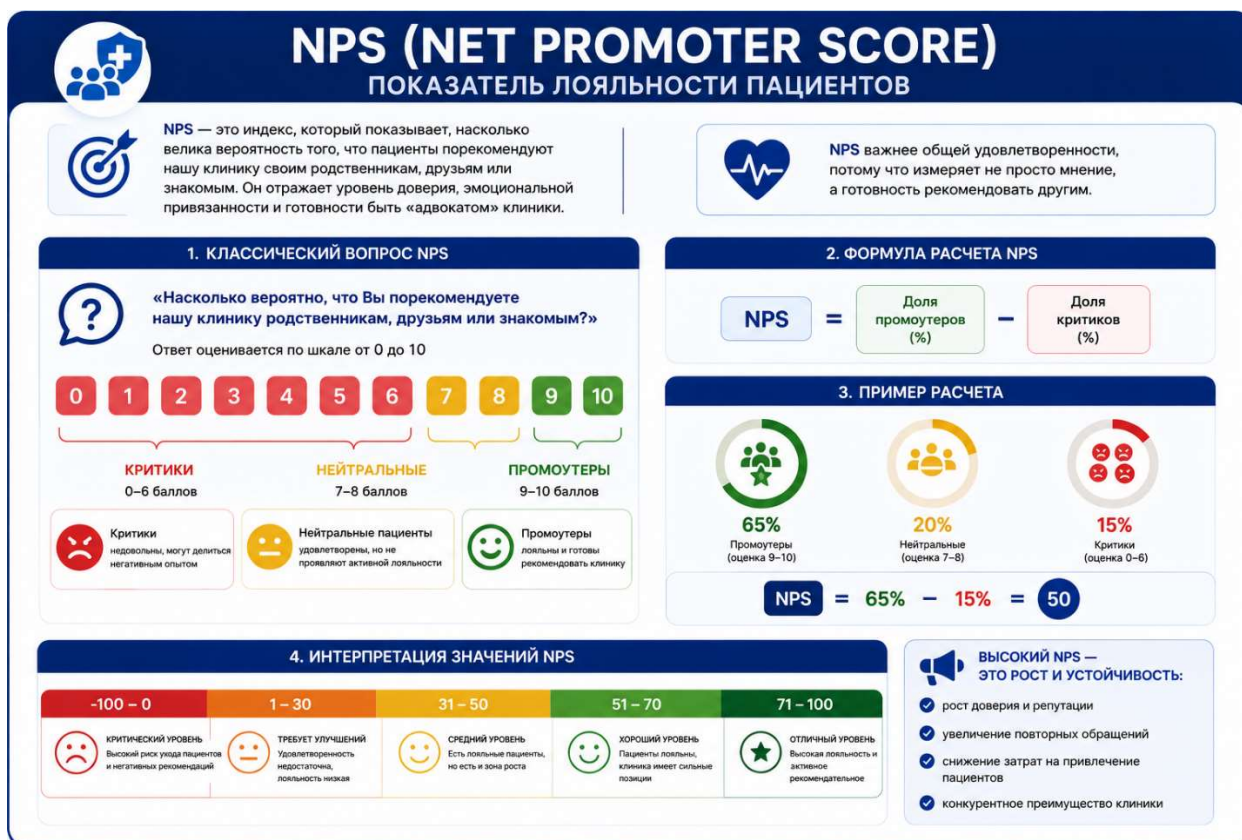


Рисунок - 1 Формула расчета показателя лояльности пациентов

Примечание: составлено автором на основе Net Promoter System® (NPS) Fred Reichheld, исследований Heskett J., Sasser W., Schlesinger L., Fornell C., Anderson E., Keiningham T. по лояльности клиентов, customer experience, relationship marketing и поведенческой экономике в сфере healthcare services

Интерпретация показателей NPS

Для медицинской организации NPS имеет важное стратегическое значение, поскольку высокий уровень лояльности снижает стоимость привлечения пациентов, повышает повторную обращаемость, укрепляет репутацию и уменьшает чувствительность пациентов к отдельным сервисным сбоям. Однако в научной литературе подчеркивается, что NPS не должен использоваться изолированно. Исследование Krol et al. показало, что NPS может быть полезным индикатором пациентского опыта, но его связь с другими измерениями опыта пациента слабее, чем у глобальной оценки и общего балла удовлетворенности; следовательно, NPS следует дополнять другими инструментами.

В контексте Clinic Miras NPS целесообразно использовать как стратегический индикатор доверия, но не как единственный показатель пациентского опыта. С учетом высокой социальной значимости медицинских услуг пациент может быть удовлетворен клиническим результатом, но недоволен доступностью, ожиданием, коммуникацией или маршрутизацией.

Полученные значения интерпретировались согласно разработанной шкале (Таблица 2).

Таблица 2 – Шкала интерпретации NPS Клиники

Значение NPS	Интерпретация	Управленческое действие
>70	высокая лояльность	поддержание сервиса, развитие программ удержания
50–70	устойчивая лояльность	анализ точек улучшения
30–49	зона внимания	аудит пациентского маршрута
0–29	риск снижения доверия	антикризисная программа пациентского опыта
<0	кризис доверия	срочная работа с качеством, жалобами и коммуникацией
<p><i>Примечание: составлено автором на основе Net Promoter Score Benchmarking System, исследований Bain & Company, Satmetrix Systems, Temkin B., Dixon M., Rawson A., Lemon K., Verhoef P. по интерпретации клиентской лояльности, patient experience analytics, сервисной устойчивости и оценке качества взаимодействия в healthcare sector</i></p>		

Анализ удовлетворенности пациентов (CSI)

CSI, или Customer Satisfaction Index, является более детализированным показателем удовлетворенности пациента конкретными аспектами взаимодействия с медицинской организацией. Если NPS отвечает на вопрос «готов ли пациент рекомендовать клинику», то CSI показывает, чем именно пациент доволен или недоволен

Для оценки удовлетворенности пациентов использовался Customer Satisfaction Index. В исследовании учитывались следующие параметры (таблица 3):

- качество медицинской помощи;
- коммуникация врача;
- доступность записи;
- время ожидания;
- сервис.

Таблица 3 – Индикаторы CSI Клиники

Блок CSI	Содержание оценки
Доступность	возможность записаться, время ожидания, удобство графика
Коммуникация	понятность объяснений врача, уважение, внимание
Организация приема	работа регистратуры, call-центра, навигация
Клинический маршрут	понятность дальнейших действий, направления, анализы
Цифровой сервис	Damumed, SMS/push-уведомления, онлайн-запись
Комфорт	чистота, навигация, условия ожидания
Безопасность	доверие к лечению, отсутствие ошибок, информированность
Общая оценка	общая удовлетворенность визитом
<p><i>Примечание: составлено автором на основе Customer Satisfaction Index (CSI) methodology, American Customer Satisfaction Index (ACSI), European Customer Satisfaction Index (ECSI), исследований Oliver R., Parasuraman A., Zeithaml V., Brady M., Bitner J., Choi K. по удовлетворенности пациентов, perceived service quality, healthcare experience measurement и сервисной эффективности медицинских организаций</i></p>	

Формула расчета CSI:

$$CSI = \frac{\sum (\text{Оценка показателя} \times \text{Вес показателя})}{\text{Максимально возможная оценка}} \times 100\%$$

Например, если пациент оценивает доступность, коммуникацию, навигацию, чистоту, качество объяснений и работу call-центра по шкале 1–5, то итоговый CSI может рассчитываться как средневзвешенный индекс

Интерпретация CSI

Предлагаемая шкала интерпретации (таблица 4):

Таблица 4 – Показатели интерпретации CSI

CSI	Интерпретация	Управленческое действие
≥90%	очень высокая удовлетворенность	поддержание стандарта
80–89%	высокая удовлетворенность	точечные улучшения
70–79%	удовлетворительно, но есть риски	анализ слабых зон
60–69%	зона неудовлетворенности	корректирующие мероприятия
<60%	кризис пациентского опыта	антикризисный план сервиса и качества
<p><i>Примечание: составлено автором на основе Healthcare Consumer Assessment Models (HCAHPS), SERVPERF methodology, исследований Anderson R., Zeithaml V., Bitner J., Rust R., Parasuraman A., Johnston R. по интерпретации удовлетворенности пациентов, сервисного качества, эмоционального восприятия медицинской помощи и устойчивости patient experience systems</i></p>		

Анализ жалоб пациентов

В ходе исследования жалобы пациентов были разделены на следующие категории: организационные; сервисные; медицинские; коммуникационные.

По данным стратегического отчета Clinic Miras, за 11 месяцев 2024 года поступило 374 обращения, из которых 258 были обработаны непосредственно службой поддержки пациента и внутреннего контроля в устном порядке «здесь и сейчас»; 63 обращения поступили через Call-центр УЗКО, 22 — через ФОМС, 21 — через E-өтініш УЗКО, 6 — через Сенім, 2 — письменно в СППВК, 1 — через E-өтініш ДККМФ и 1 — через сайт Президента. При этом 69,3% обращений закрывались на уровне клиники, а обращения составили 0,7% от прикрепленного населения.

Структура обращений в стратегическом отчете показывает, что основными зонами являются: «иное» — 102 обращения, вопросы направления к узким специалистам — 75, вопросы записи на прием семейного врача, включая длительное ожидание и отказ в приеме — 34, несвоевременное лекарственное обеспечение — 33, некачественное обследование — 29, вопросы инвалидности — 22, обслуживание на дому — 17, госпитализация — 16, некачественное лечение — 14, непредоставление разъяснений — 13 (таблица 5).

Таблица 5 - Управленческая интерпретация структуры жалоб

Категория жалоб	Возможная причина	Управленческое решение
направление к узким специалистам	дефицит слотов, слабая маршрутизация	triage, электронная очередь, контроль направлений
запись к семейному врачу	перегрузка ВОП, ограниченность расписания	перераспределение потоков, расширение записи
лекарственное обеспечение	логистические/договорные проблемы	контроль остатков, работа с ИСЛО
некачественное обследование	дефект диагностики или коммуникации	аудит протоколов и информирования
обслуживание на дому	недостаточная доступность для уязвимых групп	маршрутизация вызовов, приоритизация
некачественное лечение	клинический или коммуникационный риск	врачебная экспертиза, разбор случая
непредоставление разъяснений	слабая коммуникация	обучение врачей patient communication
<p><i>Примечание: составлено автором на основе концепции Healthcare Complaint Management, рекомендаций Joint Commission International (JCI), Agency for Healthcare Research and Quality (AHRQ), исследований Vincent C., Leape L., Hickson G., Gallagher T., Reader T., Wu A. по анализу жалоб пациентов, patient safety culture, управлению медицинскими ошибками и репутационными рисками в healthcare organizations</i></p>		

Анализ повторных обращений

Повторные обращения рассматриваются как один из наиболее объективных индикаторов доверия пациентов.

Доля повторных пациентов является одним из наиболее сильных показателей доверия. Если NPS отражает декларируемую готовность рекомендовать клинику, а CSI — удовлетворенность конкретным взаимодействием, то повторное обращение показывает реальное поведение пациента. Пациент возвращается туда, где он видит ценность, безопасность, понятность маршрута, доступность и доверие к врачу.

Доля повторных пациентов рассчитывается по формуле:

Доля повторных пациентов = Количество пациентов, обратившихся повторно / Общее количество пациентов × 100%

Дополнительно рекомендуется анализировать:

- повторные пациенты по ВОП;
- повторные пациенты по КДО;
- повторные пациенты по диагностике;
- повторные пациенты по реабилитации;
- повторные пациенты по платным услугам;
- повторные пациенты после жалобы;
- повторные пациенты после диспансерного наблюдения;
- отток прикрепленного населения.

Для Clinic Miras показатель возврата имеет особую значимость, поскольку клиника работает с прикрепленным населением и хроническими пациентами. В годовом отчете за 2024 год указано, что общее количество посещений составило 284 016, а число посещений на 1 жителя — 7,55; это отражает устойчивую интенсивность взаимодействия населения с клиникой. Дополнительно в отчете указано наличие значительного контингента пациентов, состоящих на диспансерном учете, что требует длительного повторного наблюдения и преемственности.

С антикризисной точки зрения повторный пациент является не только источником стабильного пациентопотока, но и индикатором эффективности клинической маршрутизации. Если пациент не возвращается после первичного визита, возможны несколько причин.

- проблема была решена полностью;
- пациент не получил понятного плана;
- пациент не доверяет врачу;
- пациент ушел в другую организацию;
- пациент не смог записаться повторно;
- пациент не получил напоминание;
- маршрут оказался сложным или неудобным.

Поэтому доля повторных пациентов должна интерпретироваться не механически, а с учетом клинического контекста. Для профилактических осмотров высокая доля повторов может быть не обязательной, а для хронических заболеваний, беременности, реабилитации, БСК, сахарного диабета, ХСН и туберкулеза повторное наблюдение является необходимым.

Предлагаемая управленческая интерпретация (таблица 6):

Таблица 6 – Индикаторы доли повторных пациентов Клиники

Доля повторных пациентов	Интерпретация	Возможное действие
высокая при хронических заболеваниях	хорошая преемственность	поддержание case-management
низкая при хронических заболеваниях	риск потери наблюдения	активный обзвон, push-уведомления
высокая при жалобах	возможно нерешенная проблема	аудит повторных обращений
низкая после первичных визитов	риск оттока	анализ удовлетворенности и маршрута
снижение в динамике	падение доверия или доступности	репутационный и операционный аудит
<p><i>Примечание: оставлено автором на основе концепции Patient Retention Management, моделей Continuity of Care и Relationship Marketing in Healthcare, исследований Berry L., Morgan R., Hunt S., Reichheld F., Rust R., Zeithaml V. по удержанию пациентов, повторным обращениям, patient lifetime value и формированию долгосрочного доверия к медицинской организации</i></p>		

Проведенный анализ показал, что patient trust оказывает существенное влияние на устойчивость частной медицинской организации.

Установлено, что высокий уровень доверия пациентов способствует:

- увеличению доли повторных обращений;
- повышению приверженности пациентов медицинской организации;
- снижению чувствительности к ценовым изменениям;
- повышению эффективности маркетинговых коммуникаций;
- формированию положительной цифровой репутации.

В ходе исследования выявлено, что показатели NPS и CSI тесно связаны с объемом повторных визитов и динамикой пациентопотока. Пациенты, оценивающие медицинскую организацию как надежную и безопасную, значительно чаще рекомендуют ее родственникам и знакомым, что способствует органическому росту обращаемости.

Одновременно установлено, что снижение уровня доверия сопровождается увеличением числа жалоб, снижением удовлетворенности пациентов и ухудшением репутационных показателей. В условиях кризисных ситуаций данные процессы способны усиливать организационную нестабильность и приводить к снижению финансовой устойчивости медицинской организации.

На основании проведенного анализа предложена модель оценки patient trust, включающая пять взаимосвязанных компонентов:

- удовлетворенность пациентов;
- лояльность пациентов;
- цифровая репутация;
- повторные обращения;
- структура жалоб.

Интеграция данных показателей в систему антикризисного управления позволяет своевременно выявлять признаки снижения доверия и принимать управленческие решения, направленные на повышение устойчивости медицинской организации.

Полученные результаты согласуются с исследованиями Ozawa и Gilson, согласно которым доверие пациентов оказывает непосредственное влияние на устойчивость медицинских организаций и эффективность функционирования системы здравоохранения. В отличие от существующих исследований, в настоящей работе показатели доверия пациентов интегрированы в систему антикризисного управления частной медицинской организацией.

Результаты также подтверждают данные Hall и соавт., установивших связь между доверием пациентов и приверженностью медицинской организации. Вместе с тем проведенное исследование демонстрирует дополнительное влияние patient trust на организационную устойчивость, что расширяет существующие научные представления о роли доверия пациентов в healthcare management.

Практическая модель Patient Trust Dashboard (рисунок 2)



Рисунок - 2 Контур Patient Trust Dashboard в системе MIRAS-RESILIENCE 7D

Примечание: составлено автором на основе концепции Patient Trust & Quality Management, моделей HCAHPS (Hospital Consumer Assessment of Healthcare Providers and Systems), Picker Patient Experience Framework, исследований Donabedian A., Berwick D., Safran D., Doyle C., Coulter A., Mead N. по качеству медицинской помощи, patient-centered care, доверию пациентов и оценке опыта взаимодействия с медицинской организацией

Выводы

1. Patient trust является важным фактором устойчивости частной медицинской организации.
2. Patient trust является самостоятельным стратегическим ресурсом медицинской организации.
3. Показатели NPS, CSI, повторных обращений, жалоб и цифровой репутации могут использоваться как индикаторы раннего предупреждения кризисов.
4. Предложенная система мониторинга позволяет сформировать интегральный индекс доверия пациентов.
5. Включение patient trust dashboard в систему антикризисного управления способствует повышению организационной устойчивости частной медицинской организации.
6. Разработанный подход может быть использован в медицинских организациях Республики Казахстан при формировании систем внутреннего контроля качества и риск-менеджмента.

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RETINOBLASTOMA: TOPICAL ISSUES AND THEIR SOLUTIONS

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Annotation: this scientific and analytical work presents modern clinical and diagnostic data concerning the most common malignant intraocular tumor in children – retinoblastoma. The issues of etiopathogenesis, genetic and molecular features of this pathology, assessment of the role of biomarkers in diagnostics and prognosis of the disease are covered in detail. Promising directions for the development of new and improved diagnostic and therapeutic approaches, genetic causes of this pathology, possibilities of whole genome sequencing for studying the mutation landscape, currently used classification systems of retinoblastoma, available possibilities of clinical screening are described. The publication shows that studies of the molecular basis of the disease also led to deciphering subsequent events and, thus, to the discovery of biomarkers and associated targeted therapies. In addition, improvements in molecular biology methods contributed to the development of effective methods of early diagnostics, genetic counseling and disease prevention. The issues of visual acuity assessment and improving the quality of life of patients are also comprehensively considered.

Key words: oncology, ophthalmology, retinoblastoma, incidence, etiopathogenesis, classification systems, screening, visual acuity, biomarkers, RB1 gene, DNA, genome sequencing, diagnostics, treatment, quality of life, prognosis.

Retinoblastoma (RB) is a malignant tumor of the retina in young children.

The diagnostic criteria are as follows. Complaints and anamnesis: complaints of glow in the affected eye when exposed to light, often noticed by parents when photographing a child with a flash (white pupillary reflex, leukocoria, "cat's eye symptom"), convergent or divergent strabismus, deterioration of vision; redness, hemorrhages, change in eye color, pain (not a typical symptom). It is necessary to clarify the duration of complaints, hereditary anamnesis.

Physical examination: general examination of the patient - pay attention to changes in the eye (glow when exposed to light, symmetry of the orbits, is there exophthalmos, is the eye inflamed, color of the pupil), assessment of the condition of internal organs and systems, palpation of peripheral lymph nodes - to exclude metastases. Mandatory referral to an ophthalmologist for a complete ophthalmological examination.

Laboratory tests: complete blood count - presence of anemia, moderate leukocytosis and accelerated erythrocyte sedimentation rate (for the presence/absence of inflammatory changes); biochemical blood test: liver function tests, levels of nitrogenous waste products, electrolytes, total protein and glucose - for radiological diagnostics using a contrast agent. Instrumental tests: ophthalmoscopy with pupil dilation under general anesthesia - is the most objective method for

assessing the condition of the eye - tumor size, location, prevalence, retinal detachment, condition of the optic nerve head; retinal camera - documentation of the tumor process; Ultrasound Examination of the orbits - the presence of an intraocular formation with calcifications is a pathognomic sign, the presence of retinal detachment, signs of growth into the orbit; Ultrasound Dopplerography of the orbits - presence of an intraocular formation with calcifications, determination of the tumor's own blood flow, detection of the "cut off branch" symptom, presence of retinal detachment, signs of growth into the orbit; X-ray of the chest organs, if necessary in two projections if pneumonia is suspected; magnetic resonance imaging (MRI) of the brain and orbits with contrast enhancement under anesthesia to determine the size of the formation, location, involvement of the optic nerve, presence of intracranial foci. In the absence of MRI, computed tomography (CT) of the brain and orbits may be performed, but this examination does not provide an objective assessment of the condition of the optic nerve and brain; according to indications, CT/MRI of other parts of the body in advanced cases with a long history [1].

RB is an intraocular tumor with hereditary and sporadic forms. 8,000 new cases of this ocular malignancy of the developing retina are diagnosed each year worldwide. The major gene responsible for retinoblastoma is RB transcriptional co-repressor 1 (RB1), and it harbors a large spectrum of pathogenic variants. Tumorigenesis begins with mutations that cause RB1 biallelic inactivation preventing the production of functional RB protein (pRB) [2].

pRB is a multifunctional protein involved in a variety of processes regulating cell proliferation at multiple levels including apoptosis, histone methylation and chromatin remodelling. Loss of function of pRB in the retina is thought to lead to dysregulation of these events, resulting in uncontrolled cell proliferation and chromosomal instability. The RB is the most common primary intraocular cancer of childhood, causing significant long-term sequelae. Loss-of-function mutations in RB1 are causally implicated in RB development. RB1 was the first tumour suppressor gene to be isolated, in contrast to activating oncogenes, which were characterised earlier. In humans, RB1 is located on chromosome 13q14.2, spans approximately 180 Kb and contains 27 exons encoding a 928 amino acid nucleophosphoprotein, known as pRB [3].

Depending on the type of mutation the penetrance of RB is different. However, in small percent of tumors additional genes may be required, such as MYCN, BCOR and CREBBP. Additionally, epigenetic changes contribute to the progression of RB as well. Besides its role in the cell cycle, pRB plays many additional roles, it regulates the nucleosome structure, participates in apoptosis, DNA replication, cellular senescence, differentiation, DNA repair and angiogenesis. Notably, pRB has an important role as a modulator of chromatin remodeling. In recent years high-throughput techniques are becoming essential for credible biomarker identification and patient management improvement. In spite of remarkable advances in RB therapy, primarily in high-income countries, our understanding of RB and its specific genetics still needs further clarification in order to predict the course of this disease and improve therapy. One such approach is the tumor free DNA that can be obtained from the anterior segment of the eye and be useful in diagnostics and prognostics. The field of ophthalmology genetics and genomics is expanding fast and the accumulated knowledge aims to develop novel and improved diagnostic and therapeutic approaches. The specific molecular mechanisms behind eye diseases, including RB, are being recognized every day, because it is important to understand their genetic causes and biological behavior in order to improve clinical outcome. Genetic implications for more than 97% of all RB cases is the RB1 gene inactivation. Although RB has been genetically characterized a long time ago, its molecular blueprint is still incomplete and needs deeper investigation. Several classification systems are currently in use, for example, the International Intraocular Retinoblastoma Classification (IIRC), International Classification of Retinoblastoma (ICRB) and cTNMH (American Joint Committee on Cancer (AJCC)) and for extraocular disease, the International Retinoblastoma

Staging System (IRSS) and cTNMH staging [2].

Davies H.R. et al. [3] in their study emphasize that the majority of RB1 mutations can be detected by clinical screening. However, RB cases exist where mutations in RB1 have not been detected. Our colleagues used whole-genome sequencing to investigate the landscape of mutations in a cohort of sporadic RBs, including cases where mutations in both copies of RB1 had not been previously identified. The researchers looked for mutations in cancer driver genes and revealed a wide variety of structural rearrangements disrupting RB1. In addition, they investigated mutation burden and specific mutation patterns (mutational signatures), uncovering a treatment-related mutational signature in a tumour exposed to chemotherapy. The power of whole-genome sequencing to identify RB1 mutations of all mutation types can have significant relevance to the clinical management of RB patients and genetic counselling of their families. The development of RB is thought to require pathological genetic changes in both alleles of the RB1 gene. However, cases exist where RB1 mutations are undetectable, suggesting alternative pathways to malignancy. The authors used whole-genome sequencing (WGS) and transcriptomics to investigate the landscape of sporadic RBs derived from twenty patients, sought RB1 and other driver mutations and investigated mutational signatures. At least one RB1 mutation was identified in all RBs, including new mutations in addition to those previously identified by clinical screening. Ten tumours carried structural rearrangements involving RB1 ranging from relatively simple to extremely complex rearrangement patterns, including a chromothripsis-like pattern in one tumour. Bilateral tumours obtained from one patient harboured conserved germline but divergent somatic RB1 mutations, indicating independent evolution. Mutational signature analysis showed predominance of signatures associated with cell division, an absence of ultraviolet-related DNA damage and a profound platinum-related mutational signature in a chemotherapy-exposed tumour. Most RB1 mutations are identifiable by clinical screening. However, the increased resolution and ability to detect otherwise elusive rearrangements by WGS have important repercussions on clinical management and advice on recurrence risks.

The foundational work that explained the RB inheritance but also the concept of tumor suppressor genes was originally published by Knudson in his seminal paper from 1971 Knudson's two hit model proposed that one RB1 allele is lost or mutated in all cells and a second somatic mutagenic event affects the remaining allele in a primitive retinal cell, thus initiating tumorigenesis [4].

With an average incidence of 1 in every 18,000 live births, RB is a rare type of intraocular tumour found to affect patients during their early childhood. It is curable if diagnosed at earlier stages but can become life-threateningly malignant if not treated timely. With no racial or gender predisposition, or even environmental factors known to have been involved in the incidence of the disease, RB is often considered a clinical success story in pediatric oncology. The survival rate in highly developed countries is higher than 95% and they have achieved this because of the advancement in the development of diagnostics and treatment techniques. This includes developing the already existing techniques like chemotherapy and embarking on new strategies like enucleation, thermotherapy, cryotherapy, etc. Early diagnosis, studies on the etiopathogenesis and genetics of the disease are the need of the hour for improving the survival rates. According to the Knudson hypothesis, also known as the two hit hypothesis, two hits on the susceptibility RB gene is often considered as the initiating event in the development of the disease. Studies on the molecular basis of the disease have also led to deciphering the downstream events and thus in the discovery of biomarkers and related targeted therapies. Furthermore, improvements in molecular biology techniques enhanced the development of efficient methods for early diagnosis, genetic counseling, and prevention of the disease [5].

As noted by Byroju V.V. et al. [5] with an ability to convert electromagnetic/ light energy to electrical energy, the retina acts as a transduction screen that enables the visualisation of any

object in front of it by transmitting this electrical energy as nerve impulse to the cortical functioning centres. It layers the innermost part of the eye and hosts various types of cells like rods and cones which are integral for its proper functioning. Various diseases like retinal tear, retinal detachment, diabetic retinopathy, macular degeneration, retinitis pigmentosa etc. have been associated with retina and its impaired functioning. One such disease is RB, the most common malignant intraocular tumour in children. RB is theorized to arise from the cones of the retina, which have certain properties that leave them rather susceptible to tumorigenesis. Globally, 1 in every 16,000 to 20,000 live births is known to be afflicted by RB. Most of the cases are diagnosed before the age of 5 and it accounts for 3% of all childhood cancers. Previous studies indicated that there were significant differences in the incidence of RB based on gender, ethnicity, and infections due to poor sanitation. The newer studies, however, deny significance of such differences and consider RB to have similar incidence throughout the world. Despite being rare, RB gained interest within the scientific community since RB1 gene is the first tumour suppressor gene to be discovered. In its hereditary form, RB is associated with de novo mutations resulting in tumours at other foci in the body which are termed 'second primary tumours' and is attributed to the role played by phosphorylated pRB. Subjects with hereditary RBs are at a higher risk of developing other second primary tumours such as osteosarcomas, melanomas etc.. Every form of RB, familial and sporadic has the RB gene mutated to some extent resulting in the downstream processing of aberrant transcripts. RB1 gene is located on the largest acrocentric chromosome, 13 and consists of 27 exons. Following transcription, pRB is formed and gets involved in the regulation of cell cycle at the G1-S checkpoint. Phosphorylation essentially acts to 'switch off' RB tumour suppressor protein which results in deregulation of downstream molecular events that eventually results in RB.

RB has been assigned various stages depending upon the progression of the disease and its potential for metastasis. The system was named IRSS where, the stage 0 often shows good prognosis with treatment while stage IV shows poor outcome. During stage IV, the cancer is considered to be extraocular and can lead to bulging out of the eye. When it comes to differentiating it into various types, the disease can appear as unilateral, bilateral or trilateral. The chance of a patient developing a trilateral RB is 6% higher in case of bilateral RB as compared to unilateral and can be fatal in 50% of the cases. Another classification of RB could be based on direction of progression of the disease; i.e. exophytic if the tumour originates in the retina and spreads in the direction of the brain behind or endophytic if the tissue spreads in an anatomic anterior direction [5].

In addition, a very important and even decisive aspect in the early diagnosis of RB is screening. Screening of RB involves various tests for detecting the symptoms of RB. Leukocoria (sometimes referred to as the 'cat's eye reflex') can be detected by the presence of a white reflection in photographs or the red reflex test. A simpler approach would be to use mobile phones for the same purpose where, such an application exists in the form of an app called "White eye Detector" developed by Bryan Shaw. Performing cover test detects the presence of strabismus while all other signs can be identified by a systematic visual examination. Screening by an ophthalmologist is a necessity in children with a positive family history of RB. Offspring and siblings of affected patients require regular screening examinations in childhood unless genetic testing is done to rule out a gene mutation in which case the risk is similar to that of the general population. Genetic counselling for families with RB can help determine the risk to future offspring and whether other family members are at risk of developing the disease [5,6].

An ophthalmoscope view shows the optic disk, the physiological cup, the retinal vessels, the macula and the fovea centralis so the tumour is quite easily identified. Non-invasive two dimensional and three-dimensional real-time ultrasound techniques have eased detection significantly. Once the polymerase chain reaction (PCR) was invented, it became easy to identify

the batch deletion of exons in chromosome no. 13 of the children whose parents carry the RB1 gene mutation. Quantitative multiplexing is an advanced form of the technique where several primers are used at the same time together to identify batch deletions. Use of X Ray and CT has found its place in detection of RB relying on properties such as calcification in the latter technique. Gadolinium contrast enhancement followed by MRI scanning is informative for tumor detection. Fat saturation is also very useful when fat has been suppressed at one time and expressed at another time in anticipation of tumor nature. T1-weighted imaging with magnetization is used for best results.

Fluorescein angiography is a technique that requires injection of a small bolus of fluorescent material into the blood stream which finally reaches the ophthalmic artery. A specialized camera takes pictures of the eye once it reaches there through the catheter using the fluorescence of the arteries of the eye as a light source. Unsuccessful attempts at detecting RB using positron emission tomography (PET) were made using Flourine-18-fluorodeoxyglucose (FDG) throughout many years. The conclusion that FDG-PET is not currently widely established and does not provide any significant advantage over MRI/CT except in metastasis rendered MRI as the gold standard. Early detection using an ultrasonogram in-utero to study the face and eyes can help in detection of the cancer, resulting in earlier detection and potential cure [7,8].

Vempuluru V.S., Kaliki S. [6] a PubMed search was performed to identify articles published with specific reference to screening of neonates, infants and children for RB. It has been established that various devices and mobile phone-based applications based on altered red reflex are finding their way into community screening. Diagnosis of RB by newborn eye screening is emphasized in several countries, and red reflex is the most widely employed technique. At the same time several screening programs for early detection of RB are evolving in the developing countries, but the practices are not uniform. Universal newborn screening should be the norm. Newer tools and software can be utilized to screen infants on a community scale. Focussed research on revolutionizing digital imaging for a versatile screening tool holds promise for early diagnosis of RB.

RB is a cancer that can be cured if diagnosed at an appropriate time. The involvement of structures beyond the retina and the vitreous humour should be taken into consideration as they have the potential to progress into metastasis rapidly. The treatment of RB is often complex and involves decisions to be made based on a number of factors including but not limited to the size of the tumour in various axes, age of the patient, risk of secondary metastasis, previous attempts made at chemotherapy, toxicity of the chemotherapeutic agent in the subject and laterality of the tumour. Treatment of RB includes the following aspects [6,9]:

1. *Enucleation*. Complete removal of the eye that is affected by the tumour, or surgical excision is termed as enucleation. It is the least conservative possible management and hence reserved for cases that cannot be helped otherwise. Enucleation should be avoided in cases where salvage is possible with other treatment modalities in an effort to preserve vision and improve conservation. For the first 2 years after surgery, all patients undergoing enucleation must be carefully monitored for the risk of orbital relapse. Hydroxyapatite implants coated with specialized polymers and have attachment sites for the extraocular muscles are being implemented. Overall, enucleation was widely used and continues to be used in cases where other treatment modalities are unhelpful.

2. *Intra-arterial chemotherapy (IAC)*. Intra-arterial chemotherapy is safe and effective enough to avoid enucleation. Modern microcatheter techniques are used to deliver chemotherapeutic agents, and success is achieved with acceptable toxicity. Drug choices for this route of administration typically include mephalan, topotecan hydrochloride, carboplatin, and methotrexate. This method is used as a primary or secondary therapeutic intervention. Although intra-arterial chemotherapy is an effective treatment option, its limitations require the

introduction of more sophisticated techniques. The efficacy of IAC is reduced in cases of extensive collateral meningeal vascular presence due to dilution of the agent in these vessels. Collateral blood supply to the retina other than the ophthalmic artery is variable and affects dose delivery. Catheterization of appropriate arteries requires skill, and technical difficulties may arise that may reduce the delivery of intra-arterial chemotherapy.

3. *Intravitreal chemotherapy (IVitC)*. Focused drug delivery to a vitreal seed hotspot is considered precision intra-vitreous chemotherapy and is an emerging technique. Often used as an adjunct therapy to IAC, in IVitC, drugs are delivered directly into the vitreous cavity in advanced stages of RB where vitreous seeding occurs. A combination of chemodrugs such as melphalan and topotecan are the preferred mode of treatment when tumour seeds recur in the vitreous and is found to be more effective than the respective individual treatments. While the presence of vitreous seeds is an indication for IVitC, contraindications include diffuse dispersion of the tumour seeds, invasion of the anterior chamber of the eye, hemorrhage into the vitreous humour, and secondary glaucoma. With the advent of nanoparticle delivery, IVitC has promising prospects in the management of RB.

4. *Thermotherapy*. This mode of treatment is often engaged for tumours of minor dimensions, not exclusively for the eye. The usual dimension as indicated for thermotherapy alone is of a diameter of maximum 4 mm. Diode system delivers infra-red rays either through the pupil or the sclera to destroy tumour tissue by applying focused heat to induce necrosis. Ideal temperature of thermotherapy ranges from 45-60 C. It is often used in conjunction with other treatment modalities such as chemotherapy. Complications are seen in some cases which include but are not limited to atrophy of the iris, obstruction of the retinal vein and detachment of the retina. Attempts were made to avoid thermotherapy as a single modality in cases where seeding of the vitreous humour is observed.

5. *Cryotherapy*. Much like thermotherapy, cryotherapy is an adjuvant and used in conjunction with other treatments. A RB tumour up to 3.5 mm in diameter and 2 mm in thickness could be treated with cryotherapy. This therapy is contraindicated in cases with vitreous seeding and any tumour that has dimensions larger than the norm. The modality involves the application of triple freeze thaw technique using liquid nitrogen.

6. *External beam radiation (EBR)*. EBR is in the line of management of treatment for RB after enucleation as an attempt to salvage the remaining eye. A high energy photon beam or electrons are delivered at an angle where the tumour has maximum exposure. Complications include cataracts, conjunctivitis, dry eyes and intractable glaucoma. Considering side effects such as new mutations, dry eyes, keratopathy, retinopathy and optic neuropathy, EBR therapy is better restricted to extra ocular tumour extension or if better alternatives are available, this could be completely avoided. Tumours can sometimes arise secondarily due to radiation exposure, however, development of new modalities of beam radiation reduce such instances.

The authors emphasize that tumour regression should be followed up closely and the appearance, size, location, and number of tumours documented during each examination have to be assessed. When a tumour regresses after treatment, it can either appear as a white coloured calcific mass or as translucent piece of flesh. In most of the cases, patients undergo examination under anaesthesia every 4 to 8 weeks until the age of 3, followed by less frequent examinations if the disease is found to be latent.

Ancona-Lezama D. et al. [9] in their publication emphasize that RB, the most common ocular malignancy in childhood, is lethal if left untreated. RB management remains complex, requiring individualized treatment based on ICRB staging, germline mutation status, family psychosocial factors and cultural beliefs, and available institutional resources. Management of RB remains in constant evolution and treatment can vary among different centers worldwide. However, the same primary goals of protecting life and preventing metastatic disease, followed

by globe preservation, and finally optimization of vision are commonly shared among RB specialists. The currently used therapies maintain excellent survival rates when disease is identified in the localized intraocular stage, while newer therapies have been focusing on additional improvement in globe preservation and providing the best possible visual acuity outcome. The refinement of these curative strategies has led to unprecedented cure rates and globe salvage in centers where a complete armamentarium of treatment options is available.

As noted in their study by Zhang R. et al. [10], RB is the most common intraocular malignancy in childhood. With the advanced management strategy, the globe salvage and overall survival have significantly improved, which proposes subsequent challenges regarding long-term surveillance and offspring screening. This cohort study included RB patients who visited Beijing Tongren Hospital from March 2018 to January 2022 for deep learning algorithm development. Clinical-suspected and treated RB patients from February 2022 to June 2022 were prospectively collected for prospective validation. Images from the posterior pole and peripheral retina were collected, and reference standards were made according to the consensus of the multidisciplinary management team. A deep learning algorithm was trained to identify “normal fundus”, “stable retinoblastoma” in which specific treatment is not required, and “active retinoblastoma” in which specific treatment is required. The performance of each classifier included sensitivity, specificity, accuracy, and cost-utility. A total of 36,623 images were included for developing the Deep Learning Assistant for Retinoblastoma Monitoring (DLA-RB) algorithm. In internal fivefold cross-validation, DLA-RB achieved an area under curve (AUC) of 0.998 (95% confidence interval [CI] 0.986-1.000) in distinguishing normal fundus and active RB, and 0.940 (95% CI 0.851-0.996) in distinguishing stable and active RB. From February 2022 to June 2022, 139 eyes of 103 patients were prospectively collected. In identifying active RB tumours from all clinical-suspected patients and active RB from all treated RB patients, the AUC of DLA-RB reached 0.991 (95% CI 0.970-1.000), and 0.962 (95% CI 0.915-1.000), respectively. The combination between ophthalmologists and DLA-RB significantly improved the accuracy of competent ophthalmologists and residents regarding both binary tasks. Cost-utility analysis revealed DLA-RB-based diagnosis mode is cost-effective in both RB diagnosis and active RB identification. In conclusion, the authors point out that DLA-RB achieved high accuracy and sensitivity in identifying active RB from the normal and stable RB fundus. It can be used to surveil the activity of RB during follow-up and screen high-risk offspring. Compared with referral procedures to ophthalmologic centres, DLA-RB-based screening and surveillance is cost-effective and can be incorporated within telemedicine programs.

A very important issue is the question of preserving vision in this pathology.

Sinenko I.L. et al. [11] in their work they say that it is currently treated with a limited number of drugs, adapted from other pediatric cancer treatments. Drug toxicity and relapse of the disease warrant new therapeutic strategies for these young patients. In this study, researchers developed a robust tumoroid-based platform to test chemotherapeutic agents in combination with focal therapy (thermotherapy) – a treatment option widely used in clinical practice – in accordance with clinically relevant trial protocols. The model consists of matrix-embedded tumoroids that retain RB features and respond to repeated chemotherapeutic drug exposure similarly to advanced clinical cases. Moreover, the screening platform includes a diode laser (810nm, 0.3W) to selectively heat the tumoroids, combined with an on-line system to monitor the intratumoral and surrounding temperatures. This allows the reproduction of the clinical settings of thermotherapy and combined chemothermotherapy treatments. When testing the two main drugs currently used in clinics to treat RB in our model, authors observed results similar to those clinically obtained, validating the utility of the model. This screening platform is the first system to accurately reproduce clinically relevant treatment methods and should lead to the identification of more efficient drugs to treat RB.

Schaiquevich P. et al. [12] in their work they say that the management of RB, the most

common intraocular malignancy in children, has changed drastically over the last decade. Landmark developments in local drug delivery, namely, safer techniques for intravitreal chemotherapy injection and ophthalmic artery chemosurgery, have resulted in eye globe salvages that were not previously attainable using systemic chemotherapy or external beam irradiation. Novel drugs, oncolytic viruses, and immunotherapy are promising approaches in the treatment of intraocular RB. Importantly, emerging studies of the pattern of tumor dissemination and local drug delivery may provide the first steps toward new treatments for metastatic disease. Our colleagues reviewed recent advances in RB treatment, especially with regard to local drug delivery, that have enabled successful conservative management of intraocular RB, as well as emerging data from preclinical and clinical studies on innovative approaches that promise to lead to further improvement in outcomes, namely, the mechanisms and potential uses of new and repurposed drugs and non-chemotherapy treatments, and future directions for therapeutic development.

The authors emphasize that RB has been selected as a priority tumor by the World Health Organization for its Global Initiative for Childhood Cancer. Despite being highly curable at early stages, it may be fatal if left untreated. Eye-globe salvage treatments have substantially evolved over the last few decades, making intraocular RB the most curable of all pediatric cancers in high-income countries. The development of local drug delivery methods that maximize chemotherapy exposure in the retinal, subretinal, and vitreous spaces, namely ophthalmic artery chemosurgery (OAC) and a safety-enhanced technique for intravitreal (IVI) injection, have resulted in an unprecedented rate of eye globe and vision preservation. Importantly, these new local treatments result in very high concentrations of chemotherapy in the retina and optic nerve as shown in preclinical models, preventing dissemination to the central nervous system (CNS). So far, after more than a decade of continuous use at major clinical centers around the world and after more than 200 articles published in the field, IVI and OAC have been proven safe without increasing the risk of metastatic dissemination. By eliminating the use of external beam radiotherapy and systemic chemotherapy, these treatments have improved long-term survival by reducing the incidence of treatment-associated severe toxicities, the risk of secondary malignancies, and related deaths. In contrast to this exceptional improvement in treatment outcomes, children with disseminated RB have few therapeutic options, generally limited to high-dose chemotherapy, stem cell transplant, and local radiotherapy. Even worse is the scenario for patients with metastasis in the CNS, as these patients seldom survive even with intensive therapies. Thus, newer treatments and improved methods of targeting drug delivery to the CNS may improve outcomes. Examples of CNS-targeted routes include intrathecal (IT) and intraventricular (IVt) injection, which ensure direct delivery of chemotherapy to the cerebrospinal fluid, circumventing the blood-brain barrier. OAC may also be useful in patients with orbital RB with massive optic nerve and chiasmatic tumor involvement because of maximal local exposure to chemotherapy as shown in animal models. Future clinical assessments are necessary to determine the role of local chemotherapy delivery in disseminated RB. In all cases of intraocular and extraocular disease, there is a need for new therapies that are more effective and carry less risk of toxicity. New treatment modalities, namely, targeted therapies, immunotherapy, and oncolytic viruses are emerging as possible non-chemotherapeutic options. These novel treatments may further reduce the use of cytotoxic agents, potentially leading to even higher ocular preservation rates, reduced toxicities, and prevention of tumor dissemination. Identifying high-risk features associated with tumor progression and metastasis by histopathological analysis of the enucleated eye is critical for selecting appropriate management. These approaches may soon be supplemented by circulating tumor DNA (ctDNA) analysis, which may be an early and noninvasive prognostic biomarker of treatment response and risk of occult extraocular dissemination. In addition, ctDNA may be helpful in noninvasive genomic profiling, especially to identify patients with the subtype 2 molecular signature who have an increased risk of extraocular relapse. In conclusion, the researchers

emphasize that treatments that have evolved over the last century have led to striking changes in the treatment paradigm for this ocular tumor. Advances in the knowledge of its tumor biology and drug response and the development of new routes of drug delivery promise to lead to additional new, more effective, and less toxic therapies in RB [12].

Warda O. et al. [13] in their work they say that the assessment of vision has a growing importance in the management of RB in the era of globe-conserving therapy, both prior to and after treatment. As survival rates approach 98-99% and globe salvage rates reach ever-higher levels, it is important to provide families with information regarding the visual outcomes of different treatments. As part of a holistic approach, it is essential for clinicians to understand the impact of various treatment modalities on vision, as severe visual impairment, particularly in bilateral cases, can negatively impact the child's development and overall well-being. Although family counselling often appropriately centres on saving the child's life, it is important not to let the consideration of visual outcome fall by the wayside, as this is an additional piece of information that families find useful to help guide their decisions. As the authors note visual assessment in infants can be difficult. While Snellen visual acuity is used by many studies in the ophthalmic literature, this method of quantification requires children who are old enough (often over 5 years) to co-operate. Given that RB primarily affects infants and young toddlers, methods of vision assessment need to be tailored to this age group.

Age-appropriate visual acuity (VA) assessment can be performed using standard orthoptic techniques including Cardiff Cards, Keeler Cards, Kays picture tests and Single Sheridan Gardner Tests. When possible VA should be assessed monocularly. An encouraging and animated approach is used to maximise the engagement and co-operation of the child during VA assessment. As children with RB grow older, the choice of VA assessment tool should similarly evolve to ensure the most refined quantification possible. At presentation, children with RB are often seen on an urgent basis at the RB unit, which in many cases requires them to travel a significant distance. In our service, the visual assessment is performed by the orthoptist on presentation as well as at every ophthalmological evaluation during treatment; unless systemic chemotherapy, in which case visual assessment is performed after the final cycle. When RB is in remission, a visual assessment is performed at each follow-up appointment, this takes place before the examination under anaesthesia to avoid the child and family travelling great distances twice. The assessment can prove difficult particularly for starved children before their anaesthetics, so it may be necessary to settle for binocular VA in this instance. If the quantitative assessment is not possible, qualitative methods are used i.e. fixing and following a light and different-sized target to assess for a fixation preference. During the active treatment phase, the timing of visits depends largely on the treatment modalities employed. In the later years when there is no longer ongoing active RB treatment, the frequency of visits may in some cases be driven by the need to monitor for or manage amblyopia. In addition to the subjective methods of assessing VA mentioned above, electrodiagnostic studies may occasionally be helpful. Electroretinograms (ERGs), visual evoked potentials (VEPs) and fundus fluorescein angiography (FFA) have been found to be particularly useful in assessing for retinal toxicity and visual loss following the use of intra-arterial chemotherapy in eyes with tumour-free foveolae. Whilst ERGs are recognised not to correlate with vision, VEPs have a role in infants where the foveola is not involved. In fact, VEP Spatial Frequency is better than behavioural methods up to the age of 3 and is a useful adjunct to behavioural methods in this age group when assessing novel treatments and their impact on vision [13].

In addition to appropriate timely VA assessment, screening at-risk children plays an important role in optimising visual outcomes as early diagnosis correlates with smaller tumours. Consensus-based guidelines for screening are stratified by risk category, with high-risk children being screened at 2 weeks of age and repeated every 2-4 weeks initially and then at progressively

long intervals until 5-7 years of age. While low-risk screeners are examined primarily within 4 weeks and follow-ups are dependent on genetic testing and are often awake examinations. In their conclusions and recommendations, the authors emphasize that with the increased rates of globe salvage, visual outcomes have become an integral part of planning the management for children with RB. In some situations, enucleation is still the most appropriate treatment, but with globe-conserving therapy, there is a need for information for patients and physicians alike to make informed decisions. Specialised orthoptic assessments to check visual acuity for children with RB has a very important role in the management of those cases. Thus, the prediction of the visual potential for both eyes needs to be tailored for each patient and be part of the parents' discussion and counselling. Tumour location and grading at presentation are the most important predictors of long-term visual prognosis. Age-appropriate visual assessments in infants and children with RB are important in safety profile data for new treatments. Families can be effectively counselled using the visual outcomes from treatment and where, appropriate visual rehabilitation and support can be provided; in particular liaison with nurseries/schools and local visual impairment teams [13].

As Gurney S.P. et al. [14] note in their work the goals of RB treatment are primarily to preserve life by curing the disease and preventing extraocular spread and distant metastases. Advances in treatment modalities over the past decades have improved survival rates and the goals have advanced further towards preserving eyes and improving visual outcomes. A cautious approach is therefore required to avoid changing a child's condition from that of an intraocular disease, when management is largely focused on avoiding incidence, to extraocular disease, when mortality is a significant concern. The authors point out that just over a decade ago, entering an eye with viable tumour was considered an absolute contraindication in most centres around the world. However, intraocular procedures on eyes with active disease are now performed routinely and safely, with an acceptably small risk of complications. Intravitreal administration of chemotherapy is now a well-established treatment modality for vitreous disease. More invasive intraocular surgery, such as pars plana vitrectomy and endoresection have been reported by a small number of authors for atypical circumstances, including refractory disease in a child with only one eye or when a family refuses enucleation. The place of such treatment in current practice is not established and the subject of much debate. Several surgical innovations have made intraocular procedures safer and minimised the risk of extraocular spread and metastasis. These include clear corneal incisions where possible, the use of chemotherapeutic agents in irrigation fluid during surgery and delivered to entry sites (often in combination with cryotherapy) at the end of the procedure and the prophylactic use of intravitreal chemotherapy before and after surgery. It is likely that, with the further development of safer surgical techniques, the indications for intraocular surgery in active RB will continue to broaden. Likewise, the risk-benefit analysis for intraocular surgery for inactive disease may change and result in earlier interventions to improve visual outcomes or to manage the ocular sequelae of the disease or iatrogenic complications of the treatments used in the active stage of RB.

Interesting data on the contribution to scientific research on RB were obtained through a bibliometric analysis by Gu X. et al. [15]. In their study, they attempted to analyze the research trends in the field of RB and compare the contribution of different countries, institutions, journals and authors. They extracted all publications concerning RB from 2001 to 2021 from the Web of Science database. Microsoft Excel and VOSviewer were employed to collect publication data, analyse publication trends, and visualize relevant results. A total of 1,675 publications with 30,148 citations were identified. The United States contributed the most publications (643) and citations (16,931 times) with the highest H-index value (67) as of February 4, 2021. China ranked second in the number of publications (259), while ranking fourth in both citations (2,632 times) and the H-index (26) ranked fourth. The British Journal of Ophthalmology was the most productive journal

concerning RB, and Abramson DH had published the most papers in the field. Keywords were categorized into three clusters; tumor-related research, clinical research, and management-related research. The keywords “intravitreal,” “intraarterial,” and “intravenous” appeared the most frequently, with the average appearing year being 2018.1, 2017.7, and 2017.1, respectively. Management-related research has been recognized as a heavily researched topic in the field. The study has demonstrated global trends in RB research. It has been established that the United States has been at the cutting edge of the field based on its role as the lead contributor. Despite the considerable number of publications in China, the quality of the publications requires further improvement. Novel progress can be uncovered in the *British Journal of Ophthalmology* and *Ophthalmology*. Abramson DH and Shields CL are regarded as excellent candidates for academic collaboration in the field. Chemotherapy-related research has received the most attention previously and currently; furthermore, it may still be considered in the near future as the latest hotspot.

Regarding the quality of life of patients with this pathology. Padamandala K. et al. [16] in their study note that with the increased survival of RB patients, it is important to evaluate the quality of life (QoL) of RB survivors as well as caregivers to provide comprehensive care to the children and caregivers. The aim of the study was to assess the QoL of survivors of RB, according to parents' opinions and patient self-reports, using the Pediatric QoL Questionnaire (PEDs-QoL). The study cohort included 86 RB survivors, 86 age-matched controls, and their primary carers. PedsQL 4.0 generic core scale and structured interview were administered. QoL in physical, social, emotional, and school health was evaluated and correlated with clinical and sociodemographic parameters. The mean age of the RB survivors was 5.7 years with an M:F ratio of 1.1:1. Disease was bilateral in 79% of cases. About 45% (39/86) underwent enucleation, while others received combination therapy (16; 18%), chemotherapy (30; 34%), and radiation (1; 1%). As reported by parents, the QoL of physical health domain of RB survivors was 70.2 ± 27.8 SD and 96.15 ± 13 SD, emotional health was 72.1 ± 27.4 SD and 94.4 ± 12.5 SD, social health was 80.4 ± 24.9 SD and 98.6 ± 6.2 SD; and school health was 71.9 ± 6.5 SD and 96.1 ± 12.2 SD. As per the self-report perception, the QoL of physical health was 68.2 ± 27.8 SD and 96.2 ± 13 SD, emotional health was 66.2 ± 28.4 SD and 95.3 ± 12.5 SD, social health was 69.5 ± 24.9 SD and 98.7 ± 6.2 SD, and school health was 63.5 ± 26.5 SD and 95.1 ± 12.2 SD. There was a significant relationship between enucleation and QoL domains, where $\chi^2 = 67.75$, degrees of freedom (df) = 36, and $P < 0.01$. There was a significant association between vision in the better eye (6/18 or better = 8, 6/18–6/60 = 8, 3/60 or worse = 42) and QoL scores ($\chi^2 = 95.36$, df = 62, $P < 0.01$). There was a substantial association between socioeconomic status and QoL domains, where $\chi^2 = 88.5$, df = 56, $P < 0.01$. The results of the study showed that the QoL of parents of RB survivors and self-proxy reports were negatively affected in many ways, including physical, social, emotional, and school-related dimensions. Despite the small differences, self-proxy reports indicated a lower QoL than the parents' group. The study findings indicate that there are notable correlations between enucleation and visual acuity less than 6/18, as well as socioeconomic status, with various aspects of QoL domains among individuals who have survived RB.

Dhingra H. et al. [17] in their study mention that despite high cure rates, data on health-related QoL (HRQoL) of RB survivors are limited. This study aimed to analyze parent's perspective and self-report of HRQoL of RB survivors, using healthy siblings as controls. It also evaluated the impact of socio-economic status (SES), gender, disease laterality, treatment modality, duration since diagnosis, and visual outcomes, on HRQoL. Ninety-two RB survivors were enrolled in this observational, cross-sectional questionnaire-based study conducted at a tertiary care center. QoL was analyzed in four dimensions: physical, emotional, social, and school, using both self-report (for children >6 years) and parent proxy report (for children 2-18 years) using Pediatric Quality of Life Inventory™ (PedsQL™) 4.0 Generic Core Scale. Seventy-seven healthy siblings served as

controls. The mean age of both cohorts was 5.7 years. Thirty-six (39%) patients had bilateral RB. Of the 92 survivors, 43 (47%) had undergone enucleation. The HRQoL of RB survivors was significantly lower compared to sibling controls ($P < 0.01$) in all four domains, the physical domain being most affected followed by social domain. Parents reported an inferior QoL than patient's self-report. Vision $<6/18$ in the best eye and enucleation had a negative impact on HRQoL whilst gender, disease laterality, duration since diagnosis and SES had no impact. In conclusion, our colleagues draw attention to the fact that QoL assessment is often neglected but an important aspect of survivorship. The results of this study will help in formulating awareness of the domains affected and allow timely advocacy of initiatives for addressing each issue individually. Remedial measures aimed at optimizing QoL should be incorporated as part of their rehabilitation.

Reynolds M. et al. [18] in a retrospective cohort study examined the academic performance of childhood RB survivors. Seventy-three patients with RB (median age at diagnosis 9.97 months [range 0.29, 65.1]) were followed for a median of 6.4 years (0.2, 1.76). Forty-eight (65.8%) had unilateral RB. Forty-three (63.0%) received systemic chemotherapy, 57 (78.1%) enucleation. At last follow-up, 5 (6.8%) children had bilateral VA $<20/70$. Seventeen (23.3%) reported school difficulties and 10 (13.7%) had an individualized education program (IEP). Multivariable analysis revealed that a history of receiving chemotherapy was associated with self-reported school difficulties [(odds ratio (OR) 5.44 [1.36, 21.69], $p=0.016$)], and possessing an IEP (OR 11.47 [1.34, 98.16], $p=0.03$). Degree of visual impairment and history of enucleation did not influence the risk of self-reported school difficulties or the implementation of an IEP. Among unilateral RB patients, chemotherapy was an independent risk factor for self-reported school difficulties (OR 12.8 [1.45, 113], $p=0.009$) and implementation of an IEP (OR 15.2 [0.78, 292], $p=0.02$). As the authors state, their study is significant because it is one of the first publications to look at the incidence of developmental or school delay and evidence of disease/treatment incidence, including vision loss and hearing loss, for childhood RB survivors. Further research to assess how chemotherapy treatment impacts the cognitive development of these patients is needed. The association of chemotherapy administration and school performance could potentially be explained by several factors. Patients with chemotherapy typically have more extensive disease, thus necessitating the need for multimodality therapy. Such patients may have had more extensive local therapies or radiation, which may influence the long-term cognition of a patient. Chemotherapy was typically administered on an inpatient basis. Frequent and prolonged hospitalizations involve greater disruptions in family routines, frequent separations from siblings and peers, and time away from school which could impact cognition and school performance. A study including a greater number of patients, particularly patients with more significant vision loss, could provide more information with respect to visual acuity and developmental incidence. In addition, studies looking at developmental incidence in patients treated with intra-arterial chemotherapy, whose goal is to limit systemic chemotherapy, would be beneficial. In conclusion, the authors point out the significant fact that childhood RB survivors experience educational burdens from their disease and its treatment. Efforts to assess and monitor RB survivors for evidence of cognitive impairment is needed to identify factors associated with such incidence. Identification of such factors will assist in instituting early interventions for affected patients to improve their long-term outcomes.

To summarize the above, we can conclude that RB is the most common pediatric ocular malignancy. Despite the fact that the main attention is often paid to more common oncological diseases, it is important not to forget about the need for a specialized approach to rare forms of cancer. Peculiarities of symptoms, childhood age of patients predetermine a special approach to diagnostics of this disease; aspects of oncological alertness sometimes play a decisive role not only in early diagnostics, but also in the subsequent course of this pathology and its prognosis. Variability and veiled symptoms, its similarity with various non-core processes, cause certain difficulties and lead to neglect of the disease.

In recent years, highly effective molecular genetic examination methods have become necessary for reliable identification of the oncological process by using biomarkers and, as a result, improving the results of patient treatment. At the same time, despite significant advances in the treatment of RB, understanding the mechanisms of disease progression, features of spread is necessary for further improvement of treatment methods and schemes. In terms of treatment tactics, innovative approaches to the treatment of this rare pathology are currently being developed, which at the same time is one of the most pressing problems at the intersection of modern oncology, ophthalmology and pediatrics.

Patients with RB also need long-term monitoring, since such patients have an increased risk of developing secondary malignant neoplasms during their life.

Screening by an ophthalmologist is a must for children with a positive family history of RB. Offspring, brothers and sisters of affected patients require regular screening examinations in childhood, unless genetic testing is performed to exclude a gene mutation, in which case the risk is similar to that of the general population. Genetic counseling for families with RB can help determine the risk for future offspring and whether other family members are at risk of developing the disease.

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Современные методы профилактики и лечения гипертрофических и келоидных рубцов в пластической хирургии

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Аннотация

Гипертрофические и келоидные рубцы остаются одной из актуальных проблем современной пластической, реконструктивной и эстетической хирургии. Несмотря на развитие малотравматичных хирургических технологий, совершенствование шовных материалов, внедрение лазерных, инъекционных и комбинированных методов лечения, патологическое рубцевание по-прежнему встречается у значительной части пациентов после операций, травм, ожогов, воспалительных заболеваний кожи и косметологических вмешательств. Клиническая значимость данной проблемы определяется не только эстетическим дефектом, но и функциональными нарушениями, зудом, болью, ограничением подвижности тканей, психологическим дискомфортом и снижением качества жизни пациентов.

Целью настоящего обзора является анализ современных подходов к профилактике и лечению гипертрофических и келоидных рубцов в пластической хирургии. В статье рассмотрены патогенетические механизмы патологического рубцевания, факторы риска, клинические различия между гипертрофическими и келоидными рубцами, методы оценки рубцовой ткани, а также основные направления профилактики и лечения. Особое внимание уделено силиконовой терапии, компрессионному воздействию, инъекционному введению глюкокортикостероидов, 5-фторурацила, лазерным технологиям, криотерапии, хирургическому иссечению и комбинированным схемам. Подчеркивается, что наиболее эффективной современной стратегией является индивидуализированный мультимодальный подход, основанный на типе рубца, его локализации, длительности существования, выраженности симптомов, риске рецидива и особенностях пациента.

Ключевые слова: гипертрофический рубец, келоидный рубец, пластическая хирургия, профилактика рубцов, силиконовая терапия, триамцинолон, 5-фторурацил, лазерная терапия, хирургическое лечение, патологическое рубцевание.

Введение

Формирование рубца является естественным завершающим этапом репаративного процесса после повреждения кожи. В норме рубцовая ткань постепенно созревает, становится более мягкой, бледной, плоской и менее заметной. Однако у части пациентов процесс заживления приобретает патологический характер, сопровождаясь избыточной продукцией внеклеточного матрикса, нарушением ремоделирования коллагена, длительным воспалением и формированием гипертрофических или келоидных рубцов [1, 2].

Для пластической хирургии проблема патологического рубцевания имеет особое значение. В отличие от многих других хирургических специальностей, где основной задачей является восстановление функции органа или устранение жизнеугрожающего состояния, в пластической и реконструктивной хирургии результат лечения оценивается не только по факту заживления раны, но и по эстетическому виду послеоперационного рубца. Даже технически правильно выполненная операция может восприниматься пациентом как неудовлетворительная при формировании грубого, гипертрофического или келоидного рубца. Особенно это актуально при операциях на открытых участках тела, лице, шее, ушных раковинах, груди, передней брюшной стенке, а также после реконструктивных вмешательств у пациентов молодого возраста [3].

Гипертрофические и келоидные рубцы относятся к фибропролиферативным заболеваниям кожи. Они имеют ряд общих черт: возвышаются над поверхностью кожи, отличаются плотностью, могут сопровождаться зудом, болезненностью, покраснением, чувством стягивания и косметическим дефектом. Вместе с тем между ними существуют важные клинические различия. Гипертрофический рубец, как правило, остается в пределах исходной раны, может постепенно регрессировать и лучше отвечает на консервативную терапию. Келоидный рубец выходит за границы первоначального повреждения, склонен к длительному росту, редко регрессирует самостоятельно и имеет более высокий риск рецидива после лечения [4].

Современный подход к ведению пациентов с патологическими рубцами основан на понимании того, что универсального метода лечения не существует. Эффективность терапии зависит от локализации рубца, возраста пациента, наследственной предрасположенности, фототипа кожи, выраженности механического натяжения, давности рубца, наличия воспаления, сопутствующих заболеваний и предыдущих попыток лечения [5]. В связи с этим в последние годы все большее значение приобретает персонализированный и комбинированный подход, объединяющий профилактические, консервативные, аппаратные, инъекционные и хирургические методы [6].

Материал и методы обзора

Настоящая работа представляет собой обзор литературы, посвященный современным методам профилактики и лечения гипертрофических и келоидных рубцов в пластической хирургии. При подготовке статьи были проанализированы международные клинические рекомендации, систематические обзоры, метаанализы, обзорные статьи и публикации, посвященные патогенезу, диагностике, профилактике и лечению патологического рубцевания. Особое внимание уделялось источникам, в которых рассматривались практические алгоритмы ведения пациентов, возможности комбинированной терапии, результаты применения силиконовых покрытий, компрессионной терапии, инъекционных препаратов, лазеров, криотерапии, хирургического лечения и адьювантных методов профилактики рецидивов.

Результаты

Нормальное заживление раны включает несколько последовательных фаз: гемостаз, воспаление, пролиферацию и ремоделирование. В первой фазе происходит остановка кровотечения и формирование фибринового сгустка. Затем развивается воспалительная реакция, обеспечивающая очищение раны от микробов, некротических тканей и продуктов распада. На этапе пролиферации активируются фибробласты, происходит синтез коллагена, ангиогенез и эпителизация. В фазе ремоделирования коллаген III типа постепенно заменяется более зрелым коллагеном I типа, рубцовая ткань упорядочивается, а избыток внеклеточного матрикса подвергается деградации [7].

При патологическом рубцевании этот процесс нарушается. Наиболее важную роль играют длительное воспаление, повышенная активность фибробластов и миофибробластов,

избыточный синтез коллагена, дисбаланс между матриксными металлопротеиназами и их ингибиторами, а также нарушение апоптоза клеток рубцовой ткани [8]. В результате формируется плотный фиброзный массив, который возвышается над поверхностью кожи и может сохранять признаки активности в течение длительного времени.

Одним из ключевых медиаторов фиброзного ответа является трансформирующий фактор роста β , особенно TGF- β 1. Он стимулирует пролиферацию фибробластов, их трансформацию в миофибробласты, синтез коллагена и других компонентов внеклеточного матрикса. Помимо TGF- β , в патогенезе участвуют интерлейкины, фактор роста тромбоцитов, сосудистый эндотелиальный фактор роста, механосигнальные пути, гипоксия и нарушения иммунного ответа [8, 9].

Большое значение имеет механическое натяжение тканей. Известно, что патологические рубцы чаще формируются в зонах повышенного натяжения кожи: передняя поверхность грудной клетки, плечевой пояс, верхняя часть спины, нижняя челюсть, область грудины и надлобковая зона. Механическая нагрузка поддерживает хроническое воспаление в дерме, активирует фибробласты и способствует избыточному отложению коллагена [5]. Именно поэтому современные профилактические подходы в пластической хирургии уделяют большое внимание правильному планированию разрезов, послойному закрытию раны, снижению натяжения краев, использованию поддерживающих швов, тейпирования и силиконовых покрытий.

Генетическая предрасположенность также играет существенную роль, особенно при келоидных рубцах. Келоиды чаще встречаются у пациентов с семейным анамнезом патологического рубцевания, у лиц с более темными фототипами кожи, а также у пациентов молодого возраста. Однако генетическая предрасположенность не является единственным фактором: развитие келоида требует сочетания индивидуальной чувствительности, местного повреждения, воспаления и неблагоприятных механических условий [10].

Клинические различия между гипертрофическими и келоидными рубцами

Правильное различение гипертрофических и келоидных рубцов имеет принципиальное значение, поскольку тактика лечения и прогноз у этих состояний различаются. Гипертрофический рубец обычно появляется в течение нескольких недель после операции или травмы, располагается строго в пределах исходной раны, имеет красноватый или розовый цвет, плотную консистенцию и может сопровождаться зудом. В течение месяцев или лет он может постепенно становиться более мягким, бледным и плоским [4].

Келоидный рубец, напротив, характеризуется ростом за пределы первоначального повреждения кожи. Он может появиться через несколько месяцев после травмы, прокола ушей, операции, ожога, акне или воспалительного процесса. Келоиды часто имеют блестящую поверхность, плотную консистенцию, неправильную форму, могут быть болезненными и зудящими. В отличие от гипертрофических рубцов, келоиды редко регрессируют самостоятельно и склонны к рецидиву после изолированного хирургического иссечения [6, 11].

Наиболее типичными локализациями келоидов являются мочки ушей, область грудины, плечи, верхняя часть спины, шея, нижняя челюсть. Гипертрофические рубцы могут формироваться практически в любой зоне после хирургического вмешательства, ожога или травмы, особенно если рана заживала с воспалением, натяжением или вторичным натяжением [3, 4].

В клинической практике также необходимо проводить дифференциальную диагностику патологических рубцов с дерматофибромой, дерматофибросаркомой, опухолевыми образованиями кожи, хроническими воспалительными инфильтратами и другими поражениями. При атипичном внешнем виде, быстром росте, изъязвлении,

кровоточивости или отсутствии связи с травмой целесообразно проведение биопсии и морфологического исследования [5].

Оценка рубцов в клинической практике

Для объективизации результатов лечения в пластической хирургии важно использовать стандартизированные шкалы оценки рубцов. Наиболее известной является Ванкуверская шкала оценки рубцов, включающая такие параметры, как васкуляризация, пигментация, высота и эластичность рубца. Она широко применяется при ожоговых и послеоперационных рубцах, однако не всегда отражает субъективные жалобы пациента [12].

Более комплексным инструментом является шкала POSAS — Patient and Observer Scar Assessment Scale. Ее преимущество заключается в том, что она учитывает как мнение врача, так и оценку пациента. Врач оценивает сосудистость, пигментацию, толщину, рельеф и эластичность рубца, а пациент — боль, зуд, цвет, толщину, неровность и общее восприятие рубца [12]. Для пластической хирургии такой подход особенно важен, поскольку эстетический результат во многом определяется субъективным восприятием пациента.

Кроме клинических шкал, могут использоваться инструментальные методы: фотографическая документация, ультразвуковая оценка толщины рубца, эластометрия, дерматоскопия, спектрофотометрия, трехмерная визуализация. Однако в повседневной практике наиболее доступными остаются клинический осмотр, стандартизированное фотографирование, фиксация жалоб и применение простых шкал оценки [12].

Оценка рубца должна проводиться не только до и после лечения, но и в динамике. Рубцовая ткань может изменяться в течение 12–24 месяцев, поэтому преждевременная оценка результата может быть ошибочной. При этом раннее выявление признаков патологического рубцевания позволяет своевременно начать профилактические и лечебные мероприятия, что повышает вероятность благоприятного исхода [5].

Профилактика патологического рубцевания в пластической хирургии

Профилактика гипертрофических и келоидных рубцов начинается еще на этапе планирования операции. Основная задача хирурга — создать условия для первичного заживления раны с минимальным воспалением, минимальным натяжением тканей и хорошим сопоставлением краев кожи. При плановых эстетических и реконструктивных вмешательствах необходимо учитывать линии кожного натяжения, анатомические складки и зоны, где рубец будет менее заметен [3].

Важнейшим принципом является атравматичная техника работы с тканями. Чрезмерная коагуляция, грубое обращение с краями раны, ишемия, гематома, серома и инфекция увеличивают риск патологического рубцевания. Поэтому профилактика включает тщательный гемостаз, бережную диссекцию, адекватное дренирование по показаниям, профилактику инфекционных осложнений и исключение избыточного натяжения при ушивании [1, 5].

Послойное закрытие раны с распределением нагрузки на глубокие ткани позволяет уменьшить натяжение на уровне дермы и эпидермиса. В зонах высокого риска может быть оправдано применение глубоких дермальных швов, фасциальной фиксации, Z-пластики, местных лоскутов или других методов перераспределения натяжения. Современные алгоритмы профилактики подчеркивают, что механическое натяжение является одним из ключевых управляемых факторов риска [5].

Послеоперационный уход также имеет большое значение. Пациенту следует объяснить необходимость ограничения растяжения зоны операции, защиты рубца от ультрафиолетового излучения, контроля воспаления и соблюдения рекомендаций по уходу за кожей. В течение первых месяцев после операции рубцовая ткань особенно

чувствительна к травматизации, перегреванию, мацерации, раздражающим косметическим средствам и повторному воспалению [6].

У пациентов с высоким риском келоидного рубцевания профилактика должна быть более активной. К таким пациентам относятся лица с келоидами в анамнезе, семейной предрасположенностью, темным фототипом кожи, молодым возрастом, а также пациенты, которым выполняются вмешательства в зонах высокого риска. В таких случаях целесообразно раннее использование силиконовых гелей или пластин, тейпирования, компрессионной терапии, а при первых признаках активности рубца — инъекционной или аппаратной коррекции [2, 5].

Силиконовая терапия

Силиконовые гели и силиконовые пластины являются одними из наиболее распространенных методов профилактики и лечения патологических рубцов. Их применение основано на создании тонкой полупроницаемой пленки, которая поддерживает оптимальную гидратацию рогового слоя, уменьшает трансэпидермальную потерю влаги, снижает зуд, покраснение и выраженность рубцовой гипертрофии [13].

Силиконовая терапия обычно назначается после полной эпителизации раны. Нанесение силиконового геля или использование силиконовой пластины на открытую, мокнущую или инфицированную рану недопустимо. Продолжительность применения составляет не менее 2–3 месяцев, а при склонности к гипертрофии или келоидному росту может достигать 6 месяцев и более [13].

Преимуществом силиконового геля является удобство применения на лице, шее, суставах и участках со сложным рельефом. Силиконовые пластины более удобны для плоских поверхностей и больших рубцов, однако требуют хорошей фиксации и регулярного ухода. Выбор формы силикона зависит от локализации рубца, образа жизни пациента, чувствительности кожи и вероятности соблюдения рекомендаций [2, 13].

Несмотря на широкое применение, доказательная база силиконовой терапии неоднородна. Систематические обзоры показывают, что силиконовые покрытия могут уменьшать толщину и интенсивность окраски рубцов, однако качество части исследований ограничено [13]. Тем не менее в международных рекомендациях силиконовая терапия сохраняет важное место благодаря безопасности, доступности и возможности длительного применения, особенно в профилактике послеоперационных рубцов у пациентов группы риска [1, 2].

Компрессионная терапия

Компрессионная терапия применяется преимущественно при ожоговых гипертрофических рубцах, рубцах конечностей, ушных келоидах и некоторых послеоперационных рубцах. Механизм действия связывают с уменьшением кровотока в рубцовой ткани, снижением активности фибробластов, механическим ремоделированием тканей и уменьшением отека [14].

Наиболее известным вариантом являются компрессионные garments — индивидуально изготовленные компрессионные изделия, которые применяются у пациентов после ожогов. В пластической хирургии также используются компрессионные повязки, эластичные бинты, специальные клипсы для мочек ушей после иссечения келоидов, компрессионное белье после абдоминопластики, маммопластики и других вмешательств [14].

Эффективность компрессионной терапии во многом зависит от правильного подбора давления, длительности ношения и приверженности пациента. Метод требует регулярности и может быть неудобен, особенно в жарком климате, у детей и при длительном лечении. Возможны раздражение кожи, мацерация, зуд и дискомфорт. Поэтому компрессионная

терапия должна назначаться индивидуально, с учетом локализации рубца и переносимости [14].

В профилактике рубцов после эстетических операций компрессия играет вспомогательную роль. Она может уменьшать отек, стабилизировать ткани, снижать риск сером и механического растяжения рубца. Однако ее не следует рассматривать как самостоятельный универсальный метод профилактики келоидов. Наилучшие результаты достигаются при сочетании компрессии с силиконовой терапией, контролем натяжения тканей и ранним лечением признаков гипертрофии [5, 14].

Инъекционная терапия глюкокортикостероидами

Интралезионное введение глюкокортикостероидов, прежде всего триамцинолона ацетонида, остается одним из основных методов лечения гипертрофических и келоидных рубцов. Препарат подавляет пролиферацию фибробластов, уменьшает синтез коллагена, снижает воспаление, уменьшает зуд, боль и плотность рубца [15].

Триамцинолон вводится непосредственно в толщу рубцовой ткани с интервалами обычно 3–6 недель. Концентрация и объем препарата зависят от размера, плотности и локализации рубца. При небольших и умеренно плотных рубцах могут применяться меньшие концентрации, тогда как плотные келоиды требуют более активного воздействия. Важно избегать слишком поверхностного введения, поскольку это повышает риск атрофии кожи, телеангиэктазий и депигментации [15].

Преимуществом метода является доступность, относительная простота и возможность амбулаторного применения. Однако монотерапия глюкокортикостероидами не всегда обеспечивает стойкий результат, особенно при крупных, длительно существующих и рецидивных келоидах. Кроме того, повторные инъекции могут быть болезненными и сопровождаться локальными осложнениями [6, 15].

В современной практике глюкокортикостероиды все чаще применяются в составе комбинированной терапии: с 5-фторурацилом, лазерным лечением, криотерапией, хирургическим иссечением или силиконовыми покрытиями. Такой подход позволяет повысить эффективность лечения и снизить риск побочных эффектов за счет уменьшения дозы стероидного препарата [16].

5-фторурацил и комбинированная инъекционная терапия

5-фторурацил является антиметаболитом, который подавляет пролиферацию фибробластов и уменьшает синтез внеклеточного матрикса. В лечении келоидных и гипертрофических рубцов он применяется интралезионно, как самостоятельный препарат или в комбинации с триамцинолоном [16].

Комбинация триамцинолона и 5-фторурацила рассматривается как один из эффективных вариантов лечения резистентных рубцов. Сочетание препаратов позволяет воздействовать одновременно на воспалительный и пролиферативный компоненты патологического рубцевания. По данным обзоров, комбинированная терапия может обеспечивать более выраженное уменьшение высоты, плотности, эритемы и симптомов рубца по сравнению с монотерапией стероидами [16].

Побочные эффекты 5-фторурацила включают боль при введении, жжение, гиперпигментацию, эрозии, изъязвления и локальное воспаление. Поэтому препарат должен использоваться с осторожностью, особенно на тонкой коже, в косметически значимых зонах и у пациентов с низкой переносимостью инъекций. Для уменьшения боли возможно использование местной анестезии, охлаждения или сочетания с другими методами обезболивания [16].

В пластической хирургии 5-фторурацил особенно полезен при плотных послеоперационных келоидах, рецидивных рубцах после иссечения, рубцах передней грудной стенки, плечевого пояса, ушных раковин и других зонах высокого риска. Однако

лечение должно быть курсовым, с регулярной оценкой динамики и коррекцией схемы в зависимости от ответа тканей [6, 16].

Криотерапия

Криотерапия основана на локальном воздействии низких температур, вызывающем повреждение сосудов, кристаллизацию внутриклеточной жидкости, некроз части рубцовой ткани и последующее ремоделирование. Метод используется преимущественно при небольших келоидах и гипертрофических рубцах, особенно если они имеют выраженную плотность и возвышаются над кожей [17].

Криотерапия может применяться как самостоятельный метод или в комбинации с инъекциями триамцинолона. Комбинация особенно оправдана при плотных келоидных образованиях, поскольку предварительное криовоздействие может облегчать проникновение препарата и повышать эффективность лечения [17].

Ограничениями метода являются болезненность процедуры, риск пузырей, эрозий, гипо- или гиперпигментации, особенно у пациентов с темными фототипами кожи. В косметически значимых зонах лица и шеи криотерапия должна применяться осторожно. При крупных рубцах одного криовоздействия обычно недостаточно, требуется несколько сеансов [17].

Несмотря на ограничения, криотерапия сохраняет значение как часть мультимодального лечения, особенно при небольших келоидах ушных раковин, плотных ограниченных рубцах и резистентных образованиях, плохо отвечающих на стандартную инъекционную терапию [6, 17].

Лазерные методы лечения

Лазерная терапия занимает важное место в современной коррекции рубцов. В пластической хирургии используются сосудистые лазеры, фракционные абляционные и неабляционные лазеры, CO₂-лазер, Er:YAG-лазер и комбинированные методики. Выбор лазера зависит от типа рубца, его цвета, плотности, высоты, давности, локализации и фототипа кожи пациента [18].

Сосудистые лазеры, в частности импульсный краситель на длине волны 585–595 нм, применяются при эритематозных, гиперваскулярных и зудящих рубцах. Они уменьшают сосудистый компонент, покраснение, зуд и воспалительную активность. Такие лазеры особенно полезны на ранних стадиях формирования гипертрофического рубца, когда преобладает краснота и васкуляризация [18].

Фракционный CO₂-лазер воздействует на плотность и рельеф рубца, формируя микрзоны абляции и стимулируя ремоделирование коллагена. Он может улучшать эластичность, толщину, поверхность и внешний вид рубца. Кроме того, фракционная лазерная обработка может использоваться для лазер-ассистированной доставки лекарственных препаратов, например кортикостероидов или 5-фторурацила, что повышает проникновение активного вещества в рубцовую ткань [18].

Лазерная терапия редко является единственным методом лечения выраженных келоидов. Наиболее рационально использовать ее в комбинации с силиконовой терапией, инъекциями, хирургическим лечением или послеоперационной профилактикой рецидива. При этом необходимо учитывать риск поствоспалительной гиперпигментации, особенно у пациентов с темными фототипами кожи. Неправильный выбор параметров лазера может усилить воспаление и ухудшить состояние рубца [18, 19].

Систематические обзоры показывают, что лазеры могут улучшать внешний вид и симптомы гипертрофических и келоидных рубцов, однако исследования отличаются по дизайну, параметрам воздействия и срокам наблюдения. Поэтому лазерное лечение должно рассматриваться как эффективный, но индивидуально подбираемый компонент комплексной терапии [18].

Хирургическое лечение

Хирургическое лечение применяется при рубцах, которые вызывают выраженный эстетический дефект, функциональное ограничение, контрактуру, деформацию анатомической области или не поддаются консервативной терапии. В пластической хирургии используются иссечение рубца, Z-пластика, W-пластика, локальные кожные лоскуты, пересадка кожи, дермотензия и другие реконструктивные методы [5].

При гипертрофических рубцах хирургическое лечение может быть эффективным, особенно если имеется контрактура или грубое нарушение формы тканей. Основная задача операции — не просто удалить рубец, а изменить условия заживления: снизить натяжение, правильно расположить линию разреза, улучшить качество мягкотканного покрытия и обеспечить профилактику повторной гипертрофии [5].

При келоидных рубцах изолированное хирургическое иссечение связано с высоким риском рецидива. Более того, новый келоид после операции может быть больше исходного образования. Поэтому хирургия келоидов практически всегда должна сочетаться с адьювантной терапией: послеоперационными инъекциями кортикостероидов, 5-фторурацилом, силиконовой терапией, компрессией, лазерным лечением или лучевой терапией по строгим показаниям [6, 11].

Особое значение имеет техника ушивания. Следует избегать натяжения краев кожи, использовать послойное закрытие, при необходимости — глубокие поддерживающие швы. В зонах высокого риска может применяться перераспределение линии рубца с помощью Z-пластики или местных лоскутов. После операции необходимо длительное наблюдение, поскольку рецидив келоида может развиваться в течение месяцев [5].

Хирургическое лечение наиболее оправдано при крупных одиночных келоидах, келоидах мочки уха, рубцовых контрактурах, деформирующих рубцах после травм и ожогов, а также при рубцах, нарушающих функцию или затрудняющих ношение одежды, очков, слуховых аппаратов и других изделий. При множественных келоидах хирургия должна применяться ограниченно и только как часть комплексного плана [6].

Лучевая терапия как адьювантный метод

Послеоперационная лучевая терапия применяется в ряде клиник для профилактики рецидива келоидов после хирургического иссечения. Ее эффект связан с подавлением пролиферации фибробластов и снижением синтеза коллагена в ранний послеоперационный период [20].

Наиболее часто лучевая терапия рассматривается при рецидивных, крупных или трудно поддающихся лечению келоидах, особенно в зонах с высоким риском повторного роста. При этом из-за потенциальных рисков метод требует строгого отбора пациентов, информированного согласия, учета возраста, локализации, суммарной дозы, радиочувствительности окружающих тканей и онкологической настроженности [20].

В пластической хирургии лучевая терапия не является методом первой линии и не применяется рутинно для всех пациентов. Она должна рассматриваться только в случаях, когда ожидаемая польза превышает потенциальные риски, а другие методы лечения имеют низкую вероятность успеха. Особенно осторожно следует подходить к применению у детей, беременных, пациентов с рубцами вблизи молочной железы, щитовидной железы и половых органов [20].

Наилучшие результаты описаны при сочетании хирургического иссечения и ранней послеоперационной лучевой терапии, проводимой в первые сутки или ближайшие дни после операции. Однако из-за различий в протоколах, дозах и методах облучения универсальной схемы для всех пациентов не существует [20].

Перспективные и дополнительные методы

Помимо классических методов, активно изучаются новые подходы к лечению патологических рубцов. К ним относятся ботулинический токсин типа А, блеомицин, интерфероны, верапамил, митомицин С, плазмотерапия, жировая трансплантация, стволовые клетки, таргетная антифибротическая терапия и методы молекулярного воздействия на сигнальные пути фиброза [6, 9, 21].

Ботулинический токсин может снижать механическое натяжение тканей за счет временного расслабления мышц, а также оказывать влияние на активность фибробластов. В пластической хирургии это направление представляет интерес для профилактики послеоперационных рубцов в зонах мимической активности, а также для коррекции уже сформированных гипертрофических рубцов. Однако оптимальные дозы, точки введения и показания требуют дальнейшего изучения [21].

Блеомицин применяется интралеззионно и обладает антипролиферативным действием. Он может быть эффективен при резистентных келоидах, однако его применение ограничено болезненностью, риском пигментных изменений, локальных некрозов и необходимостью строгого соблюдения техники введения [22].

Аутологичная жировая ткань и стромально-васкулярная фракция рассматриваются как перспективные методы улучшения качества рубцов, особенно при втянутых, болезненных, плотных и посттравматических рубцах. Предполагается, что жировая ткань может улучшать трофику, эластичность, васкуляризацию и качество мягких тканей. Однако при истинных келоидах эти методы пока не могут рассматриваться как стандарт лечения [6].

Перспективным направлением является таргетное воздействие на молекулярные механизмы фиброза: TGF- β /Smad-сигналинг, Wnt/ β -катенин, механотрансдукцию, воспалительные цитокины и регуляцию активности фибробластов. Однако большинство таких методов пока находятся на экспериментальной или ранней клинической стадии [9].

Комбинированный подход как современный стандарт

Современная концепция лечения патологических рубцов основывается на том, что монотерапия редко обеспечивает стойкий результат, особенно при келоидных рубцах. Наиболее рациональным является комбинированный подход, при котором разные методы воздействуют на различные звенья патогенеза: механическое натяжение, воспаление, сосудистый компонент, активность фибробластов, синтез коллагена и ремоделирование тканей [5, 6].

Например, при раннем гипертрофическом рубце после операции может быть достаточно силиконовой терапии, тейпирования и наблюдения. При нарастании плотности и зуда добавляются инъекции триамцинолона или лазерное воздействие. При выраженной эритеме целесообразен сосудистый лазер, а при плотном возвышающемся рубце — фракционный CO₂-лазер, инъекции или их комбинация [18].

При небольшом келоиде возможна комбинированная инъекционная терапия триамцинолоном и 5-фторурацилом, криотерапия или лазерное лечение. При крупном одиночном келоиде может рассматриваться хирургическое иссечение с обязательной послеоперационной профилактикой рецидива. При множественных келоидах предпочтение часто отдается консервативной и симптоматической терапии, направленной на уменьшение боли, зуда, воспаления и объема рубцовой ткани [6].

Комбинированная терапия должна быть не хаотичной, а этапной. На первом этапе необходимо оценить тип рубца, активность процесса и жалобы пациента. На втором этапе выбрать базовый метод: силикон, компрессия, инъекции, лазер или операция. На третьем этапе определить методы профилактики рецидива и сроки наблюдения. Такой алгоритм позволяет уменьшить риск избыточного лечения и повысить предсказуемость результата [5].

Практический алгоритм ведения пациента с патологическим рубцом

В практической работе пластического хирурга можно использовать следующий подход.

Первый этап — оценка рубца и факторов риска. Необходимо уточнить давность рубца, причину его формирования, наличие келоидов в анамнезе, семейную предрасположенность, фототип кожи, локализацию, симптомы, предыдущее лечение и ожидания пациента. Обязательно проводится фотофиксация и, по возможности, оценка по шкале VSS или POSAS [12].

Второй этап — определение типа рубца. Если рубец находится в пределах раны, постепенно уменьшается и не имеет признаков прогрессии, вероятнее всего речь идет о гипертрофическом рубце. Если образование выходит за пределы повреждения, продолжает расти, сопровождается зудом и болью, следует предполагать келоид [4].

Третий этап — выбор профилактической или лечебной тактики. При свежем послеоперационном рубце у пациента группы риска целесообразны силиконовая терапия, тейпирование, защита от ультрафиолета и контроль натяжения. При ранней гипертрофии добавляются инъекции или лазер. При сформированном келоиде предпочтение отдается комбинированному лечению [5, 6].

Четвертый этап — динамическое наблюдение. Пациент должен понимать, что лечение рубцов требует времени. Оценка результата после одной процедуры часто некорректна. Необходимы повторные визиты, коррекция схемы и длительная профилактика рецидива. Особенно это касается келоидных рубцов, где риск повторного роста сохраняется длительное время [6].

Пятый этап — коррекция ожиданий пациента. Важно объяснить, что полное исчезновение рубца невозможно. Цель лечения — сделать рубец более плоским, мягким, светлым, менее болезненным и менее заметным, а также улучшить функцию и качество жизни. Реалистичное информирование пациента повышает удовлетворенность результатом и снижает риск конфликтных ожиданий [12].

Значение профилактики в эстетической хирургии

В эстетической хирургии профилактика рубцов имеет особое значение, поскольку даже небольшое ухудшение качества рубца может отрицательно повлиять на восприятие результата операции. После абдоминопластики, маммопластики, блефаропластики, подтяжки лица, отопластики и других вмешательств пациент ожидает не только улучшения формы, но и малозаметного послеоперационного следа.

На этапе планирования эстетической операции необходимо выявлять пациентов с высоким риском патологического рубцевания. Если у пациента ранее были келоиды после прокола ушей, акне, травм или операций, это должно быть обязательно учтено при выборе доступа и объема вмешательства. В некоторых случаях наличие выраженной склонности к келоидам может быть относительным противопоказанием к необязательным эстетическим операциям в зонах высокого риска [3, 5].

После операции пациент должен получить четкие рекомендации по уходу за рубцом: когда начинать силиконовую терапию, сколько времени ее продолжать, как ограничивать натяжение, когда можно возвращаться к физическим нагрузкам, как защищать рубец от солнца и в каких случаях необходимо срочно обратиться к врачу. Покраснение, нарастание зуда, уплотнение и возвышение рубца должны рассматриваться как ранние признаки патологического процесса [5].

Таким образом, профилактика патологического рубцевания в эстетической хирургии должна быть не дополнительной опцией, а обязательной частью хирургического плана. Именно ранняя профилактика позволяет избежать сложного, длительного и не всегда

предсказуемого лечения сформировавшегося келоида или грубого гипертрофического рубца.

Заключение

Гипертрофические и келоидные рубцы представляют собой сложную клиническую проблему, находящуюся на стыке пластической хирургии, дерматологии, комбустиологии, реконструктивной хирургии и эстетической медицины. Их развитие связано с нарушением нормального процесса заживления, хроническим воспалением, избыточной активностью фибробластов, повышенным синтезом коллагена, механическим натяжением тканей и индивидуальной предрасположенностью пациента.

Современные методы профилактики включают правильное планирование хирургического доступа, атравматичную технику, снижение натяжения краев раны, профилактику воспалительных осложнений, силиконовую терапию, тейпирование, компрессию и динамическое наблюдение. Лечение сформированных рубцов может включать инъекции глюкокортикостероидов, 5-фторурацила, криотерапию, лазерные технологии, хирургическое иссечение и адьювантные методы профилактики рецидива.

Наиболее эффективной стратегией является индивидуализированный мультимодальный подход. Выбор метода должен зависеть от типа рубца, локализации, давности, выраженности симптомов, эстетического и функционального дефекта, риска рецидива и ожиданий пациента. Для гипертрофических рубцов часто достаточно ранней консервативной и аппаратной коррекции, тогда как келоидные рубцы требуют более длительного, комбинированного и осторожного лечения.

В пластической хирургии профилактика патологического рубцевания должна рассматриваться как важнейший элемент качества хирургического результата. Ранняя диагностика, стандартизированная оценка рубца, грамотное информирование пациента и применение доказательных комбинированных методов позволяют улучшить эстетические и функциональные исходы, снизить частоту рецидивов и повысить качество жизни пациентов.

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ШҰБАТ ҮЛГІЛЕРІНДЕГІ АНТИБИОТИКТЕРГЕ ТӨЗІМДІЛІК ГЕНДЕРІНІҢ ӘРТҮРЛІЛІГІ МЕН ТАРАЛУЫН ТАЛДАУ

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Аннотация

Шұбат түйе сүтінен дайындалатын дәстүрлі ашытылған сусын. Оның микробиотасы өнім сапасын қалыптастырумен қатар, антибиотиктерге төзімділік гендерінің ықтимал көзі ретінде де қызығушылық тудырады. Бұл жұмыста Қазақстанның Қызылорда, Түркістан және Алматы облыстарынан жиналған жеті шұбат үлгісіндегі антибиотиктерге төзімділік гендері метагеномдық секвенирлеу әдісімен зерттелді. Алынған деректер антибиотиктерге төзімділік гендерінің дерекқорымен салыстырылып, олардың құрамы мен салыстырмалы молшылығы бағаланды.

Талдау нәтижесінде барлық үлгілерден антибиотиктерге төзімділіктің 351 гені анықталды. Олардың ішінде *acr*, *bacA*, *rosAB*, *ImrP* және *emeA* гендері басым кездесті. *ImrP* және *emeA* гендерінің таралуы сәйкесінше *Lactococcus lactis* және *Enterococcus faecalis* түрлерінің молшылығымен байланысты болды. Барлық үлгілерде жоғары деңгейде анықталған *bacA* гені бацитрацинге төзімділікпен байланысты болуы мүмкін. Зерттеу нәтижелері шұбат микробиотасында антибиотиктерге төзімділік гендерінің кең таралғанын және олардың шығу тегі мен таралу жолдарын тереңірек зерттеу қажеттігін көрсетеді.

Түйінді сөздер: шұбат, метагеномика, антибиотиктерге төзімділік гендері, микробиота, секвенирлеу.

1 Кіріспе

Антибиотиктердің клиникалық тәжірибеге енгізілуі жұқпалы аурулардан болатын өлім-жітімді едәуір төмендетіп, медицина тарихындағы ең ірі жетістіктердің біріне айналды. Дегенмен соңғы онжылдықтарда антибиотиктерді медицинада, ветеринарияда және мал шаруашылығында кең көлемде пайдалану микроорганизмдердің бейімделу қарқынын күшейтті. Соның нәтижесінде көптеген бактериялар бұрын тиімді болған препараттарға төзімділік танытып, антибиотиктерге төзімділік жаһандық деңгейдегі денсаулық сақтау

мәселесіне айналды [1]. Мұндай өзгерістер емдеу нәтижелеріне ғана емес, ауруханаға жатқызу ұзақтығына, емдеу шығындарына және инфекциялық аурулардың таралу динамикасына да әсер етеді [2].

Төзімділік құбылысы тек патогенді микроорганизмдермен шектелмей, антибиотиктерге төзімділік гендері табиғи экожүйелерде, ауыл шаруашылығы жануарларының микробиомында, су көздерінде және тағам өнімдерінде де кездеседі [3]. Соңғы жылдары зерттеушілердің назары ферменттелген тағамдарға да ауып отыр. Себебі мұндай өнімдерде бактериялардың көптүрлі қауымдастықтары қалыптасады және олардың арасында генетикалық материал алмасуы жүруі мүмкін. Әсіресе плазмидалар мен басқа белсенді генетикалық элементтер арқылы төзімділік гендерінің бір түрден екіншісіне берілу ықтималдығы қауіпсіздік тұрғысынан назар аудартуда [4].

Қазақстанда кең таралған дәстүрлі ашытылған сүт өнімдерінің бірі – шұбат. Бұл өнім түйе сүтінің табиғи ашуы нәтижесінде түзіледі және оның микробтық құрамы өндіріс тәсіліне, географиялық аймаққа, шикізат сапасына және ашыту жағдайларына байланысты өзгеріп отырады. Шұбатта сүтқышқылды бактериялар мен ашытқылардың басым болуы оның дәмдік қасиеттерін қалыптастырып қана қоймай, микробтық экожүйесінің тұрақтылығына да ықпал етеді. Соңғы жылдары шұбат микробиотасының таксономиялық құрылымы мен пробиотикалық әлеуетіне қатысты зерттеулер жарияланғанымен, антибиотиктерге төзімділік гендерінің таралуы жөніндегі деректер әлі де шектеулі [5].

Осындай міндеттерді шешуде метагеномдық секвенирлеу әдістері кеңінен қолданылып келеді. Нәтижесінде жеке микроорганизмдердің таксономиялық құрамын ғана емес, олардың функционалдық әлеуетін, соның ішінде антибиотиктерге төзімділікпен байланысты гендерді де анықтауға болады [6].

Осы зерттеуде Қазақстанның әртүрлі өңірлерінен жиналған шұбат үлгілеріндегі антибиотиктерге төзімділік гендерінің құрамы мен таралу ерекшеліктері метагеномдық секвенирлеу негізінде бағаланды. Сонымен қатар анықталған гендердің салыстырмалы молшылығы мен олардың ықтимал микробтық тасымалдаушылары арасындағы байланыс қарастырылды.

2 Материалдар мен әдістер

2.1 Шұбат үлгілерін жинау

Зерттеу үшін Қазақстанның үш облысындағы жеті түрлі өңірден жергілікті тұрғындар дайындаған шұбат үлгілері жиналды. Үлгілер Алматы облысынан (S10, S11, S13, S16), Қызылорда облысынан (S12) және Түркістан облысынан (S14, S15) алынды. Әрбір үлгі алдын ала мұқият араластырылып, стерильді пипетка көмегімен 50 мл көлемінде зарарсыздандырылған түтікшелерге құйылды. Бір аймақтан алынған үлгілер біріктіріліп, ортақ зерттеу үлгісі қалыптастырылды. Үлгілер алдын ала салқындалатылып, мұздатқыш элементтері бар контейнерлер арқылы зертханаға жеткізілді және талдау жүргізілгенге дейін –80 °C температурада сақталды.

2.2 Жалпы ДНҚ-ны бөліп алу және секвенирлеу

Шұбат үлгілерінен жалпы микробтық ДНҚ E.Z.N.A. Stool DNA Kit жинағының хаттамасына сәйкес бөлініп алынды. Бөлініп алынған ДНҚ-ның тазалығы мен концентрациясы NanoDrop 2000 спектрофотометрі арқылы анықталды. ДНҚ тұтастығы 1% агарозалық гель электрофорезі көмегімен бағаланды. Концентрацияны нақтылау үшін Qubit 3.0 флуориметрі қолданылды. Кітапхана дайындау барысында ДНҚ фрагменттері шамамен 350 жұп нуклеотид ұзындығына дейін ұсақталды. Nextera XT DNA Library Preparation Kit көмегімен секвенирлеу кітапханалары дайындалып, кейін Illumina жоғары өнімді секвенирлеу платформасында талданды.

2.3 Метагеномдық деректерді өңдеу

Алынған бастапқы секвенирлеу деректері сапалық бақылаудан өткізілді. Төмен сапалы ридтер, адаптерлік тізбектер және ұзындығы 75 жұп нуклеотидтен қысқа фрагменттер талдаудан шығарылды. Тазартылған деректер негізінде геномдық құрастыру Megahit бағдарламасы арқылы жүргізілді. Ашық оқу шеңберлері (ORF) MetaProdigal бағдарламасы көмегімен анықталды. Ұзындығы 100 жұп нуклеотидтен асатын гендер әрі қарай талдауға енгізілді. Барлық үлгілерден алынған гендер CD-HIT бағдарламасы арқылы кластерленіп, 95% ұқсастық деңгейінде редундантты емес гендер жиынтығы құрылды. Гендердің салыстырмалы молшылығы Salmon бағдарламасы арқылы есептелді.

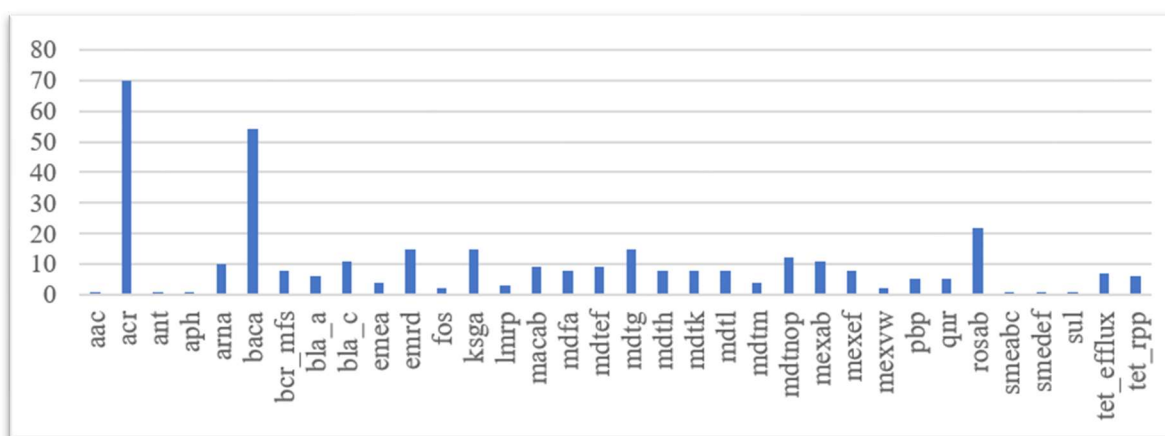
2.4 Антибиотиктерге төзімділік гендерін анықтау

Антибиотиктерге төзімділік гендерін анықтау үшін алынған гендер жиынтығы Antibiotic Resistance Genes Database (ARDB) дерекқорымен салыстырылды. Сәйкестендіру BLASTx алгоритмі негізінде жүргізілді. Сенімді сәйкестік ретінде E-value < 10⁻⁵, аминқышқылдық ұқсастық ≥90% және кемінде 25 аминқышқылынан тұратын тураланған аймақ қабылданды. Нәтижесінде анықталған төзімділік гендерінің саны, типтері және функционалдық ерекшеліктері бағаланды.

3 Нәтижелер және талқылау

3.1 Шұбат үлгілеріндегі антибиотиктерге төзімділік гендерінің таралуы

Метагеномдық талдау нәтижесінде зерттелген жеті шұбат үлгісінен антибиотиктерге төзімділікке қатысты 351 ген анықталды. Олардың ішінде *acr* тобына жататын 70 ген, *bacA* тобына жататын 54 ген және *rosAB* тобына жататын 22 ген тіркелді (1-сурет). Анықталған гендер жалпы алғанда 34 функционалдық класқа тиесілі болды, олардың қатарында *aac*, *acr*, *ant*, *aph*, *arnA*, *bacA*, *blaA*, *blaC*, *emrD*, *fos*, *ksgA*, *lmpP*, *macAB*, *mdfA*, *mdtEF*, *mdtG*, *mdtH*, *mdtK*, *mdtL*, *mdtM*, *mdtNOP*, *mexAB*, *mexEF*, *mexVW*, *pbp*, *qnr*, *rosAB*, *smeABC*, *smeDEF*, *sul*, *tet-efflux* және *tetRPP* сияқты гендер бар.



1-сурет. Барлық шұбат үлгілерінде антибиотикке төзімділік гендерінің көптігі анықталды

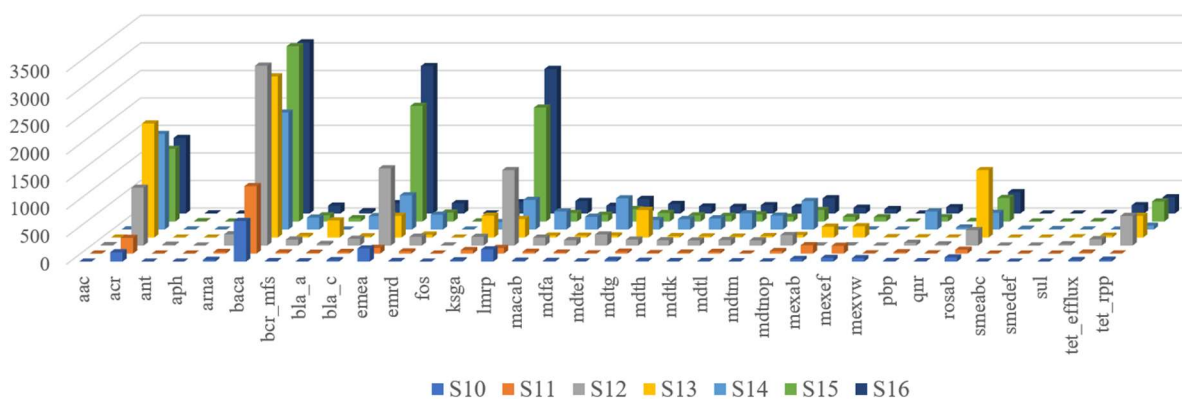
Барлық жеті үлгіде бір мезгілде анықталған гендердің саны 23 болды (1-кесте). Бұл гендер шұбат микробиотасының тұрақты компоненттерімен байланысты болуы мүмкін. Сонымен қатар кейбір гендердің тек жекелеген өңірлерде кездесуі антибиотиктерге төзімділік гендерінің таралуына географиялық жағдайлар, өндіріс технологиясы немесе микробтық қауымдастықтардың құрамы әсер етуі ықтимал екенін көрсетеді.

1-кесте. Әрбір үлгідегі кейбір дәріге төзімді гендердің таралуы

Үлгілер	Жалпы саны (гендер түрі)	Антибиотикке төзімді генлер
S10, S11, S12, S13, S14, S15, S16	23	<i>lmp, arna, emrd, mdtef, mdtm, mdfa, rosab, baca, mdth, mdtnop, emea, mdtg, bla_c, macab, bcr_mfs, tet_rpp, ksga, acr, mdtk, mexef, pbb, mdl</i>
S10, S11, S12, S13, S15, S16	3	<i>mexab, bla_a, tet_efflux</i>
S12, S13, S14, S15, S16	1	<i>sul</i>
S10, S11, S15, S16	1	<i>mexvw</i>
S12, S14, S15, S16	2	<i>aac</i>
S10, S15, S16	1	<i>fos</i>
S10, S14	1	<i>smeabc</i>
S14	1	<i>smedef</i>

3.2 Басым антибиотиктерге төзімділік гендерінің салыстырмалы молшылығы

ARDB дерекқорымен жүргізілген салыстыру нәтижесінде барлық үлгілерде төрт геннің - *bacA*, *acr*, *emeA* және *lmp* - молшылығы басқа гендермен салыстырғанда едәуір жоғары екені анықталды (2-сурет).



2-сурет. Шұбат үлгілеріндегі антибиотиктерге төзімділік гендерінің салыстырмалы көптігі

Ең жоғары көрсеткіш *bacA* геніне тиесілі болды. Барлық үлгілер бойынша бұл генге сәйкес келетін 16586 тізбек анықталды. Оның ішінде S12, S15 және S16 үлгілерінде *bacA* генінің саны ерекше жоғары болды. Ал *acr* генінің молшылығы S13 және S14 үлгілерінде басым байқалды. *lmp* және *emeA* гендері негізінен S15 және S16 үлгілерінде жоғары деңгейде тіркелді.

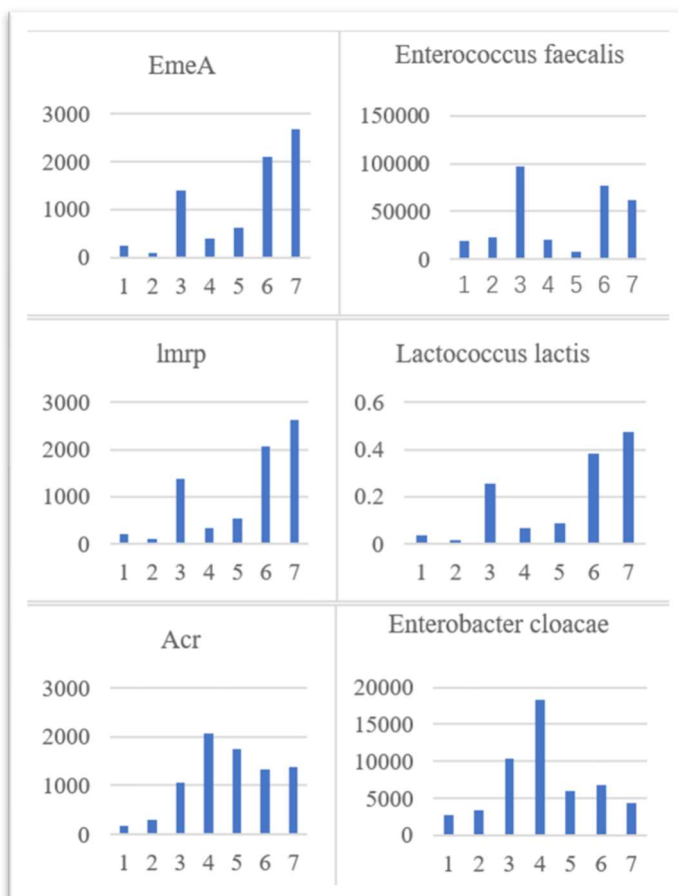
Бұл төрт геннің ішінде *acr*, *lmp* және *emeA* көпдәрілік төзімділікпен байланысты эфлюкс-тасымалдаушы жүйелердің құрамына кіреді. Мұндай жүйелер бактерия жасушасына енген ұлы қосылыстарды, соның ішінде антибиотиктерді сыртқа шығару арқылы жасушаның тіршілік қабілетін сақтайды. Сондықтан олардың жоғары молшылығы тек антибиотиктер қысымының нәтижесі ғана емес, микроорганизмдердің табиғи физиологиялық бейімделу механизмдерімен де байланысты болуы мүмкін.

3.3 Антибиотиктерге төзімділік гендері мен микробтық қауымдастық арасындағы байланыс

Корреляциялық талдау нәтижелері антибиотиктерге төзімділік гендерінің таралуы белгілі бір микроорганизмдердің молшылығымен байланысты екенін көрсетті (3-сурет). Атап айтқанда, *ImrP* және *emeA* гендерінің салыстырмалы молшылығы сәйкесінше *Lactococcus lactis* және *Enterococcus faecalis* түрлерінің үлесімен оң корреляция көрсетті.

Мұндай сәйкестік кездейсоқ құбылыс емес. Кейбір зерттеулерде белгілі бір төзімділік гендерінің таралуы оларды тасымалдаушы микроорганизмдердің таралу динамикасымен қатар жүретіні көрсетілген [7]. Сондықтан гендердің салыстырмалы молшылығын талдау кезінде микробтық қауымдастық құрылымын да ескеру қажет. Соңғы онжылдықта *Lactococcus lactis* грамоң бактериялардағы көпдәрілік төзімділік жүйелерін зерттеудің негізгі модельдерінің біріне айналды [8]. Бұл микроорганизмде *LmrA* және *LmrP* деп аталатын екі негізгі тасымалдаушы жүйе сипатталған. Олар көптеген катиондық липофильді қосылыстарға және клиникалық тәжірибеде қолданылатын бірқатар антибиотиктерге төзімділік қалыптастырады [9]. Біздің зерттеуде анықталған *ImrP* генінің жоғары молшылығы осы бактериялардың шұбат микробиотасындағы елеулі үлесімен байланысты болуы мүмкін.

Осыған ұқсас жағдай *emeA* геніне де тән. *EmeA* жүйесі *Enterococcus* туысына жататын бактерияларда кездесетін көпдәрілік эфлюкс-сорғы ретінде сипатталған. Зерттеу нәтижелері бойынша *Enterococcus faecalis* мөлшері жоғары үлгілерде *emeA* генінің де жоғары деңгейде анықталуы осы байланысты жанама түрде растайды.



3-сурет. Шұбат үлгілерінде салыстырмалы түрде көптігі жоғары бірнеше антибиотикке төзімділік гендерінің салыстырмалы көптігі және олардың ықтимал шығу тегі бактерияларының талдауы

3.4 *Acr* жүйесінің таралу ерекшеліктері

Зерттеу барысында *acr* генінің молшылығы *Enterobacter cloacae* секілді Enterobacteriaceae тұқымдасының кейбір өкілдерінің таралуымен байланысты екені байқалды (3-сурет). Бұл нәтиже әдеби деректермен сәйкес келеді.

AcrAB-TolC жүйесі грамтеріс бактерияларда кең таралған үш компонентті көпдәрілік эффлюкс кешені ретінде белгілі. Бұл жүйе антибиотиктерді ғана емес, бояғыштарды, жуғыш заттарды, дезинфекциялаушы заттарды және басқа да уытты қосылыстарды жасушадан шығаруға қатысады [10]. Сондықтан оның болуы әрдайым антибиотиктер қысымының тікелей көрсеткіші бола бермейді.

Қазіргі уақытта мұндай тасымалдаушы жүйелердің табиғи қызметіне қатысты екі түрлі көзқарас бар. Бірқатар зерттеушілер оларды антибиотиктерге төзімділіктің негізгі механизмі ретінде қарастырса, басқа авторлар бұл жүйелер бастапқыда қоршаған ортадағы улы гидрофобты молекулалардан қорғану немесе белгілі бір метаболиттерді тасымалдау үшін қалыптасқан деп есептейді. Антимикробтық заттарды шығару қабілеті кейінірек пайда болған қосымша қасиет болуы мүмкін [11].

3.5 *bacA* генінің жоғары молшылығының ықтимал себептері

Барлық үлгілерде *bacA* генінің жоғары деңгейде кездесуі зерттеудің ең қызықты нәтижелерінің бірі болды. Дегенмен бұл геннің молшылығы оның ықтимал тасымалдаушылары ретінде қарастырылатын *Bacillus amyloliquefaciens* және *Bacillus subtilis* түрлерінің мөлшерімен сәйкес келмеді.

bacA гені бацитрацинге төзімділікпен байланысты. Оның өнімі жасуша қабырғасының биосинтезі кезінде ундекапренил-пирофосфаттың қайта айналымына қатысып, бактерияның бацитрацин әсеріне төтеп беруіне мүмкіндік береді. Бацитрацин көптеген елдерде ауыл шаруашылығында жемдік қоспа ретінде пайдаланылғандықтан, *bacA* генінің кең таралуы осы тәжірибемен байланысты болуы ықтимал.

Түйелердің негізгі азығы табиғи жайылым өсімдіктері болғанымен, олар басқа ауыл шаруашылығы жануарларымен ортақ экожүйеде тіршілік етеді. Сондықтан антибиотиктерге төзімділік гендерін тасымалдаушы микроорганизмдердің жануарлар арасында немесе қоршаған орта арқылы таралу мүмкіндігін жоққа шығаруға болмайды. Сонымен қатар соңғы зерттеулер көпдәрілік тасымалдаушы жүйелердің антибиотиктерге төзімділікпен қатар жасушаішілік рН тұрақтылығын сақтауға да қатысатынын көрсеткен. Мысалы, *Lactococcus lactis* бактериясындағы *LmrA* жүйесі дәрілік заттар мен протондардың бірлескен тасымалын жүзеге асырып, жасушаның энергетикалық тепе-теңдігіне әсер етеді [209]. Сондықтан анықталған кейбір төзімділік гендері антибиотиктер қысымының ғана емес, микроорганизмдердің табиғи физиологиялық бейімделуінің де көрсеткіші болуы мүмкін.

4 Қорытынды

Қазақстанның әртүрлі өңірлерінен жиналған шұбат үлгілерінің метагеномдық талдауы нәтижесінде антибиотиктерге төзімділіктің 351 гені анықталды. Ең жоғары таралған гендер ретінде *bacA*, *acr*, *ImrP* және *emeA* гендері тіркелді. Кейбір гендердің белгілі микроорганизмдермен корреляциясы олардың ықтимал шығу көздерін анықтауға мүмкіндік берді. Зерттеу нәтижелері шұбат микробиотасында антибиотиктерге төзімділік гендерінің кең таралғанын көрсетті. Бұл дәстүрлі ферменттелген өнімдердің микробиологиялық қауіпсіздігін бағалау және антибиотиктерге төзімділіктің таралу жолдарын түсіну үшін маңызды ғылыми деректер болып табылады. Болашақта төзімділік гендерінің тасымалдану механизмдерін және олардың қоғамдық денсаулыққа ықпалын тереңірек зерттеу қажет.

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The Post-CRISPR Toolkit: Prime Editing, RNA Editing, and Programmable Integration

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Abstract

The rapid evolution of genome engineering has extended the field beyond conventional CRISPR-Cas9 nucleases toward a broader set of precision editing platforms. Although CRISPR-Cas9 transformed modern molecular biology by enabling programmable DNA cleavage, its reliance on double-strand breaks and endogenous repair pathways can produce undesired insertions, deletions, chromosomal rearrangements, and inconsistent editing outcomes (Lee et al., 2025; Chen et al., 2024). In response, new editing modalities have emerged to improve precision, flexibility, and safety in both experimental and therapeutic settings. Among these, prime editing offers a search-and-replace strategy capable of introducing precise substitutions, small insertions, and deletions without requiring donor DNA templates or double-strand DNA cleavage (Lee et al., 2025). In parallel, RNA editing platforms, including ADAR-based systems and CRISPR-Cas13-derived approaches, provide reversible correction at the transcript level and may reduce the long-term risks associated with permanent genome modification (Booth et al., 2023; Lo et al., 2022; Yang & Patel, 2024). Complementing these tools, programmable integration systems such as PASTE and CRISPR-associated transposon platforms are designed to overcome a major limitation of classic editing methods: the efficient, site-specific insertion of larger genetic payloads (Yarnall et al., 2023; Wang et al., 2023). Together, these technologies represent a conceptual shift from DNA cutting alone toward precise rewriting, reversible transcript correction, and targeted genomic installation. This article introduces the major components of the post-CRISPR toolkit and outlines their significance for the future of precision medicine, functional genomics, and next-generation gene therapy (Anzalone et al., 2019; Chen & Liu, 2023; Booth et al., 2023; Yarnall et al., 2023).

Keywords: prime editing; RNA editing; programmable integration; post-CRISPR technologies; genome engineering; transcriptome editing; PASTE; gene therapy

Introduction

From programmable cutting to precision rewriting

Since its adaptation for genome engineering, CRISPR-Cas9 has fundamentally changed the biological sciences by making targeted DNA modification faster, more accessible, and more scalable than earlier nuclease platforms such as zinc-finger nucleases and TALENs. Its simplicity and programmability accelerated applications in basic research, disease modeling, crop engineering, and translational medicine. However, the standard CRISPR-Cas9 framework is still largely dependent on generating double-strand breaks and exploiting endogenous DNA repair pathways, especially non-homologous end joining and homology-directed repair. These repair processes can be unpredictable and may generate unwanted by-products, including indels, large deletions, rearrangements, and variable knock-in efficiencies, particularly in therapeutically

relevant or non-dividing cell types (Anzalone et al., 2019; Rees & Liu, 2018; Bennett et al., 2020; Lee et al., 2025; Chen et al., 2024).

Why a post-CRISPR toolkit became necessary

These limitations have motivated the development of a broader post-CRISPR toolkit in which editing outcomes are no longer restricted to nuclease-mediated cutting. Prime editing is one of the most influential advances in this transition. By combining a Cas9 nickase with a reverse transcriptase and a prime editing guide RNA, prime editing enables the installation of defined sequence changes without creating double-strand breaks or relying on donor DNA templates. This architecture greatly expands the range of possible edits and includes precise substitutions, small insertions, and deletions. As a result, prime editing has become especially attractive for modeling pathogenic variants and correcting disease-associated mutations with improved control over editing outcomes (Anzalone et al., 2019; Chen & Liu, 2023; Zhao et al., 2023; Lee et al., 2025).

At the same time, RNA editing has emerged as a complementary approach that shifts intervention from the genome to the transcriptome. Rather than permanently modifying DNA, RNA editing operates post-transcriptionally and therefore offers a reversible form of molecular correction. Current systems include ADAR-mediated editing, CRISPR-Cas13-based methods, antisense-guided approaches, and related programmable RNA-targeting strategies. Because edited transcripts are naturally degraded over time, RNA editing may be advantageous in settings where transient regulation is preferred or where permanent genome alteration raises safety concerns. This reversibility makes RNA editing particularly appealing for neurological disorders, immune diseases, and other contexts in which fine control over duration and dosage may be clinically important (Cox et al., 2017; Booth et al., 2023; Lo et al., 2022; Yang & Patel, 2024) (Fig 1).

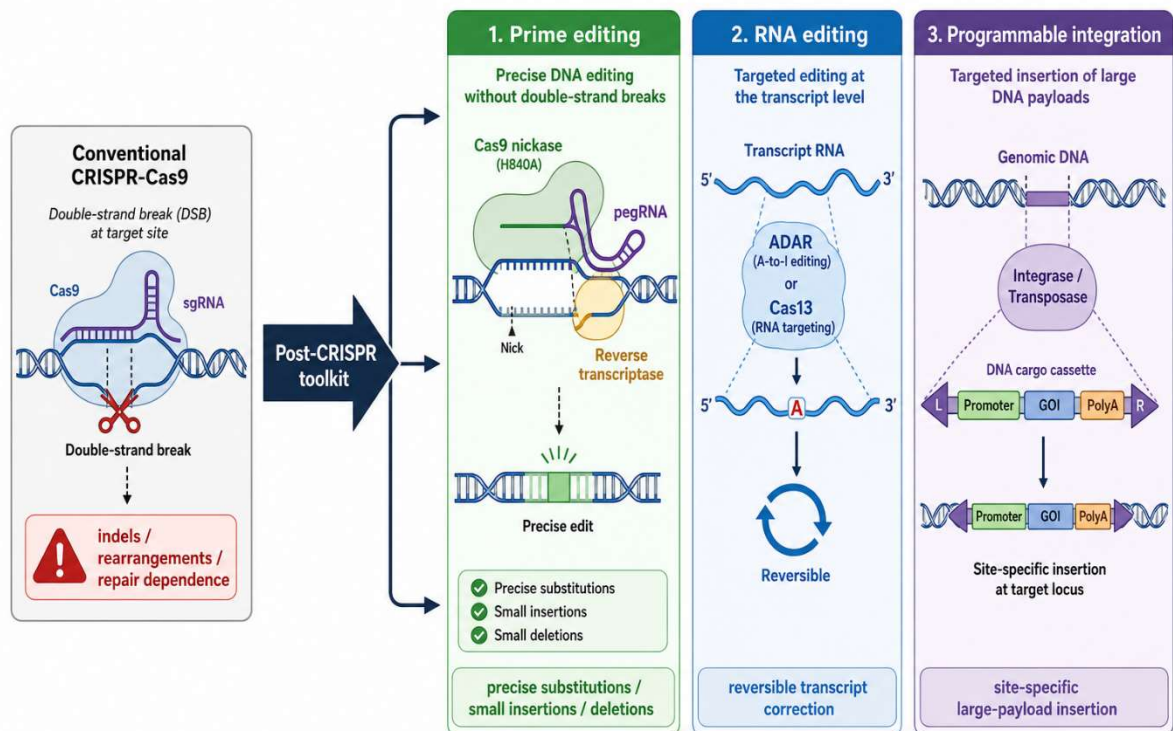


Figure 1. The post-CRISPR toolkit: from DNA cleavage to precise rewriting, reversible transcript correction, and targeted integration. The figure contrasts conventional CRISPR-Cas9, which depends on double-strand DNA breaks and endogenous repair, with three newer editing modalities. Prime editing enables precise DNA sequence rewriting without double-strand breaks; RNA editing provides reversible correction at the transcript level; and programmable integration supports targeted insertion of larger genetic payloads. Together, these platforms

extend genome engineering beyond nuclease-mediated cutting toward more precise, modular, and clinically adaptable interventions.

A further frontier in the post-CRISPR landscape is programmable integration, which addresses one of the most persistent challenges in genome engineering: the efficient and targeted insertion of large DNA cargos. Conventional knock-in strategies based on homology-directed repair are often inefficient and highly context dependent. In contrast, newer systems such as PASTE integrate the targeting ability of CRISPR with reverse transcription and serine integrases to enable large, site-specific DNA insertion without double-strand DNA cleavage. Related developments in CRISPR-associated transposons and other large-sequence insertion technologies further expand the possibilities for gene replacement, multiplex engineering, and synthetic biology applications (Yarnall et al., 2023; Wang et al., 2023; Chen et al., 2024). Collectively, prime editing, RNA editing, and programmable integration do not replace CRISPR; rather, they extend its legacy into a more precise, modular, and clinically adaptable framework for next-generation genetic medicine (Yarnall et al., 2023; Wang et al., 2023; Hsieh & Peters, 2024).

Why the field moved beyond double-strand breaks

Limits of the first-generation editing paradigm

The earliest wave of CRISPR engineering was powered by a simple and powerful idea: create a site-specific DNA break, then allow the cell to repair it. That logic remains useful for gene disruption and for some knock-in workflows, yet it places the biological outcome under the partial control of endogenous repair pathways that differ by cell type, cell-cycle state, chromatin environment, and disease context. In practice, the same nuclease can generate multiple repair products, producing heterogeneous alleles within a single sample. This variability complicates disease modeling, weakens therapeutic consistency, and raises the burden of downstream molecular characterization. The field therefore began to seek editing systems that would preserve programmability while reducing dependence on unpredictable repair outcomes (Anzalone et al., 2019; Bennett et al., 2020).

The move beyond double-strand breaks also reflects a safety argument. DNA cleavage can trigger p53 activation, chromosomal translocations, large deletions, and rearrangements that are difficult to detect with short-read assays alone. In research settings, these issues may be manageable through careful screening. In therapeutic settings, however, every additional layer of uncertainty becomes a translational obstacle. Precision medicine increasingly requires not only that an editor reaches the intended site, but also that it does so with a defined product spectrum, a predictable dose response, and a risk profile compatible with long-term follow-up. Post-CRISPR systems respond to this need by reframing genome engineering as targeted writing, transcript correction, or guided integration rather than as cleavage alone (Bennett et al., 2020; Yu et al., 2020).

Conceptually, this shift broadens what counts as an editing event. A desired intervention may involve replacing one pathogenic base, restoring a transient RNA transcript, or inserting an intact regulatory cassette at a genomic safe harbor. These goals demand different molecular machines. The post-CRISPR toolkit therefore represents diversification rather than replacement: classical CRISPR remains valuable, but it is increasingly joined by specialized platforms designed for higher precision, reversibility, or larger genetic payloads.

Prime editing

Core molecular logic and modular design

Prime editing is frequently described as a search-and-replace strategy because it couples sequence recognition to local DNA synthesis rather than to blunt cutting. The canonical system combines a Cas9 nickase with a reverse transcriptase and uses a prime editing guide RNA, or pegRNA, to specify both the genomic target and the intended edit. After the nickase creates a single-strand break, the exposed DNA end hybridizes to a primer-binding sequence within the

pegRNA, enabling the reverse transcriptase to copy the desired edit into DNA. Cellular flap resolution and mismatch processing then help convert the intermediate into a stable edited product. This architecture expands the editable space beyond simple disruption and enables substitutions, small insertions, and small deletions within one programmable framework (Anzalone et al., 2019; Chen & Liu, 2023).

A central strength of prime editing is that its information content is distributed across several tunable components. The spacer directs target recognition, the primer-binding site affects initiation efficiency, the reverse-transcription template encodes the new sequence, and additional nicking strategies can bias repair toward the edited strand. Because the edit is explicitly written into the pegRNA, prime editing offers a conceptual advantage for precise variant installation. Researchers can test disease alleles, correct pathogenic mutations, or introduce synonymous changes that prevent recutting, all without requiring an external donor template. In that sense, prime editing occupies a middle ground between base editing and homology-directed repair, combining greater edit versatility than the former with less reliance on double-strand repair than the latter.

The modularity of prime editing also makes it an engineering platform rather than a single reagent. Laboratories routinely optimize pegRNA architecture, scaffold stability, expression cassette design, and nicking configuration to improve activity in specific cells. This modular behavior explains why prime editing has progressed rapidly: every part of the system can be refined independently while the overall logic remains intact.

Figure 2. Molecular mechanism and component architecture of prime editing

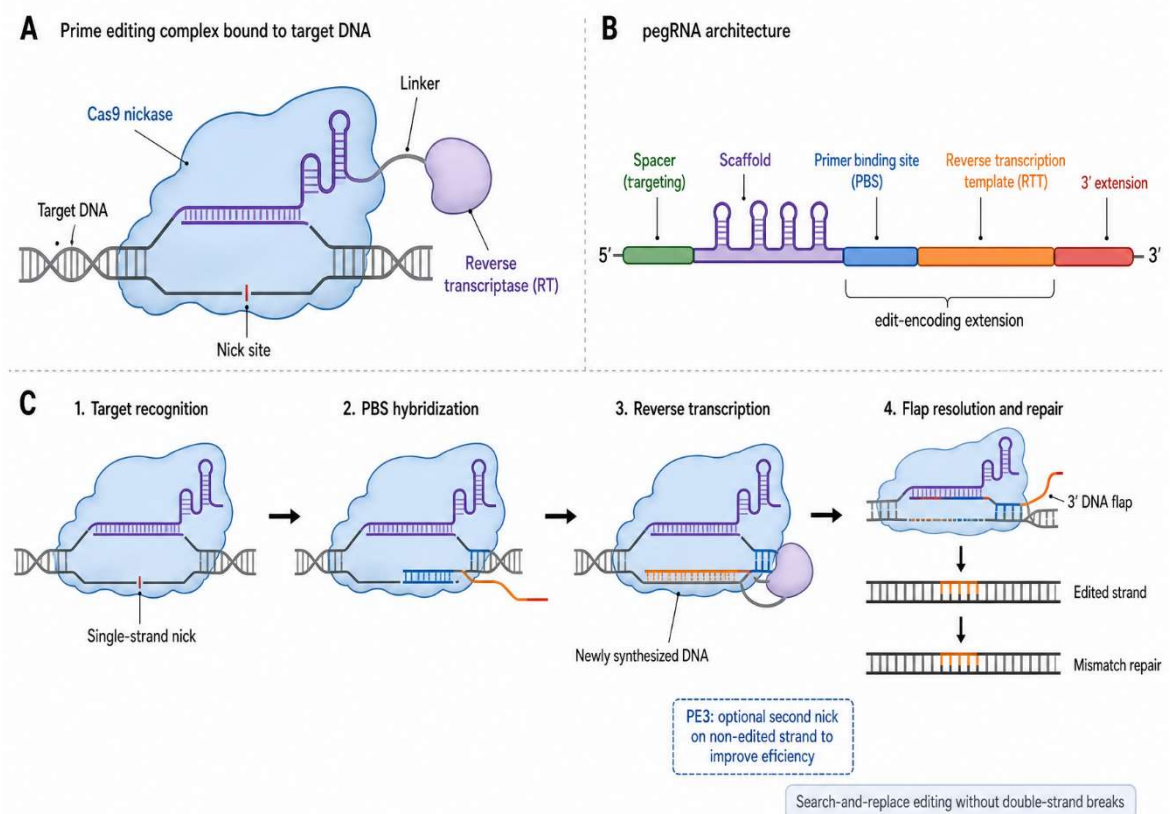


Figure 2. Molecular mechanism and component architecture of prime editing. Prime editing uses a Cas9 nickase fused to reverse transcriptase (RT) together with a prime editing guide RNA (pegRNA) to install precise sequence changes without creating a double-strand break. The pegRNA contains a targeting spacer, scaffold, primer binding site (PBS), and reverse transcription template (RTT), which together guide recognition of the genomic target and encoding of the intended edit. Following nicking, the exposed DNA end hybridizes to the PBS, reverse transcription copies the RTT into DNA, and flap resolution plus repair pathways produce

the edited sequence. An optional PE3 strategy introduces a second nick on the non-edited strand to improve efficiency.

Prime editing

pegRNA architecture, repair bias, and product purity

The pegRNA is more than a targeting guide; it is the central instruction set of prime editing. Small changes in primer-binding-site length, reverse-transcription-template sequence, and local secondary structure can substantially alter editing efficiency. If the primer-binding region is too short, annealing may be unstable. If it is too long, productive extension can decrease. Likewise, the reverse-transcription template must encode the desired product while minimizing sequence features that favor mispriming, hairpin formation, or unintended by-products. Because these variables depend on local sequence context, pegRNA design remains partly empirical even as computational tools improve (Adikusuma et al., 2021; Chen & Liu, 2023; Lee et al., 2025).

A second determinant is how the cell resolves the DNA intermediates created during prime editing. After reverse transcription, the locus contains competing 3-prime and 5-prime flaps that must be processed. The balance between edited and unedited outcomes depends on endonuclease activity, mismatch repair status, and the timing of nicking on the non-edited strand. Strategies such as PE3 and related variants introduce a second nick to encourage fixation of the edited sequence, but this can also increase unwanted insertions or deletions if timing and geometry are suboptimal. Product purity therefore becomes as important as gross efficiency, especially when prime editing is developed for therapeutic use.

These design considerations have practical consequences for review writing and for experimental planning. A locus that appears theoretically editable may still require multiple pegRNA iterations before acceptable performance is achieved. For this reason, the modern prime-editing workflow often combines computational design, pooled screening, and deep sequencing. The best-performing editor is rarely the first design on paper; it is the result of iterative tuning that balances activity, specificity, and manufacturability.

Prime editing

Platform variants and performance tuning

After the initial disclosure of prime editing, numerous variants were developed to improve efficiency, broaden targeting scope, and simplify delivery. Some designs enhance reverse-transcriptase performance or stabilize pegRNA structure, whereas others modify the Cas protein to recognize a wider set of protospacer-adjacent motifs. Additional versions alter the relationship between nicking and flap resolution, aiming to improve installation of challenging edits or reduce indel formation. Collectively, these variants show that prime editing is not a static method but an evolving family of tools tailored to different sequence contexts and biological systems (Scholefield & Harrison, 2021; Zhao et al., 2023; Zeng et al., 2024).

Performance tuning usually involves several layers. At the protein level, codon optimization, linker architecture, nuclear localization signals, and promoter choice can affect editor abundance and intracellular trafficking. At the RNA level, pegRNA stabilization motifs, chemically protected ends, or expression from alternative transcription systems may improve persistence and folding. At the cellular level, transient modulation of mismatch repair, chromatin accessibility, or cell-cycle state can reshape the editing landscape. The most successful protocols therefore integrate molecular design with cell biology rather than treating the editor as an isolated reagent.

An important lesson from these improvements is that apparent inefficiency often reflects a mismatch between editor architecture and biological context. A prime editor that performs well in immortalized cell lines may not transfer directly to stem cells, primary hepatocytes, or differentiated neurons. Consequently, variant selection should be guided by the intended endpoint. Disease modeling may prioritize speed and multiplexability, whereas therapeutic

correction may prioritize product purity, dose minimization, and compatibility with clinically realistic delivery platforms.

Prime editing

Delivery strategies for experimental and therapeutic use

Delivery remains one of the main determinants of whether prime editing stays a laboratory method or becomes a widely deployable therapeutic modality. The prime editor protein is large, the pegRNA is structurally elaborate, and many target tissues are difficult to transfect. Plasmid delivery is convenient for cell culture but poorly suited to clinical use. Viral vectors can improve tissue access, yet cargo limits and prolonged expression may create new problems. For these reasons, the field is actively comparing DNA, mRNA, ribonucleoprotein, and hybrid delivery formats in pursuit of the best balance between potency and control (Herrera-Barrera et al., 2023; Masarwy et al., 2024; Zeng et al., 2024).

In *ex vivo* workflows, electroporation of mRNA and synthetic guide molecules offers an attractive compromise because it can generate high transient expression while limiting prolonged editor activity. This format is especially appealing for hematopoietic or immune-cell engineering, where edited cells can be quality controlled before reinfusion. *In vivo* delivery is more demanding. Dual-vector systems, split editors, virus-like particles, and lipid nanoparticles are all under investigation as ways to move large editors into clinically relevant tissues. Each route changes the risk profile. Longer expression windows may improve conversion at difficult loci, but they can also increase off-target exposure or immune recognition.

Delivery challenges also shape which diseases are currently realistic targets. Liver-directed applications benefit from a relatively mature nucleic-acid delivery ecosystem, whereas the central nervous system, muscle, and lung still pose substantial barriers. As a result, the progress of prime editing will depend not only on enzyme design but also on the parallel maturation of tissue-specific delivery technologies and manufacturing methods that can reproducibly package complex editor systems at scale.

Prime editing

Research applications and therapeutic prospects

Prime editing is especially powerful in settings where investigators need exact alleles rather than approximate perturbations. In functional genomics, the system can introduce clinically observed point mutations, revert them to wild type, or create matched coding and noncoding variants for causal testing. Because the edit is defined at nucleotide resolution, prime editing supports cleaner genotype-phenotype comparisons than conventional knockout approaches. It is therefore well suited to studying regulatory elements, splice junctions, enhancer grammar, and pathogenic missense variation that cannot be captured by complete gene disruption (Chen & Liu, 2023; Newby & Liu, 2021; Lee et al., 2025).

Therapeutically, prime editing is attractive because many inherited disorders are driven by relatively small sequence changes. A tool capable of installing precise substitutions or short corrective insertions could in principle address large classes of monogenic disease without the unpredictability associated with double-strand-break repair. The approach may be especially valuable when the goal is to restore normal gene function while preserving endogenous regulation. Instead of adding an extra cDNA copy under an artificial promoter, prime editing can potentially repair the native locus and maintain physiological expression patterns across development and tissue states.

At the same time, translational optimism must be matched by realistic appraisal. Editing efficiency thresholds differ by disease, with some disorders requiring correction in only a small fraction of cells and others demanding broad tissue coverage. Product purity, by-product characterization, re-dosing feasibility, and long-term surveillance will determine where prime editing first succeeds clinically. Even so, its conceptual fit with precision medicine is unusually

strong: it promises not merely to disable genes, but to write specific therapeutic sequences into their natural genomic context.

RNA editing

Reversible correction at the transcript level

RNA editing occupies a distinctive place in the post-CRISPR toolkit because it targets gene expression after transcription rather than altering the underlying genome. This makes the intervention inherently reversible. Edited transcripts are diluted by RNA turnover, allowing clinicians and researchers to modulate effect duration through delivery schedule rather than permanent DNA change. Such reversibility can be an advantage when the safety of lifelong genome modification is uncertain or when transient correction is sufficient to achieve therapeutic benefit. It also offers a valuable experimental strategy for probing gene function without creating irreversible genomic scars (Booth et al., 2023; Lo et al., 2022; Khosravi & Jantsch, 2021).

The best-studied programmable RNA editing systems often build on adenosine deaminases acting on RNA, especially ADAR enzymes, which catalyze adenosine-to-inosine conversion in double-stranded RNA contexts. Because inosine is read as guanosine by cellular machinery, this chemistry can recode selected bases in transcripts, restore protein function, or modulate splice patterns. Other approaches enlist CRISPR-associated RNA-targeting proteins, antisense oligonucleotides, or engineered recruitment scaffolds to position catalytic domains near a chosen transcript. Together, these strategies broaden the definition of therapeutic editing from permanent rewriting to controlled transcript remodeling (Cox et al., 2017; Aquino-Jarquín, 2020; Chen et al., 2019).

The transcript-level focus of RNA editing changes both the opportunity and the limitation profile. Repeated dosing may be required, but reversibility may reduce concern about irreversible off-target damage. The most suitable indications are therefore not always the same as those for DNA editing. Disorders involving dosage-sensitive proteins, episodic pathology, or tissues where permanent DNA editing remains difficult may particularly benefit from RNA-based correction strategies.

RNA editing

ADAR recruitment systems and evolving design principles

Programmable ADAR recruitment has become a leading strategy for transcriptome editing because it builds on a catalytic activity that already exists in mammalian cells. One design philosophy uses engineered guide RNAs or antisense molecules to create the double-stranded RNA structures that ADAR prefers. Another attaches ADAR catalytic domains to programmable RNA-binding proteins, thereby improving target selectivity and local concentration. In both cases, the key design challenge is to create enough pairing or recruitment to support efficient deamination while avoiding excessive editing of nearby adenosines. Precision is therefore a function of both chemistry and RNA structure (Aquino-Jarquín, 2020; Tang et al., 2021; Booth et al., 2023).

Guide design in RNA editing differs from guide design in DNA editing because the target is dynamic. Transcript abundance, isoform diversity, splicing status, RNA localization, and secondary structure all influence accessibility. An editable codon in one isoform may be effectively invisible in another, and a guide that performs well in overexpression systems may underperform against endogenous transcripts. Successful RNA editing platforms must therefore account for transcript biology rather than relying only on genomic sequence. This requirement has encouraged the integration of transcriptome mapping, isoform-aware design, and structure-informed prediction into RNA-editing workflows.

A further consideration is catalytic scope. Classical ADAR-mediated editing is strongest for A-to-I conversion, which is powerful but not universal. As the field matures, investigators are expanding the range of programmable RNA chemistries and improving the controllability of ADAR-

based systems with inducible expression, localization signals, and context-sensitive guide architectures. These advances suggest that RNA editing may evolve from a niche complement to DNA editing into an independent therapeutic platform with its own best-practice design rules.

RNA editing

Cas13 and broader programmable RNA targeting

CRISPR-Cas13 systems expanded the RNA-engineering field by providing a programmable protein scaffold that naturally recognizes RNA rather than DNA. When catalytically active, Cas13 can cleave targeted transcripts and support knockdown applications. When catalytically altered or fused to effector domains, the same targeting logic can be repurposed for transcript editing, base conversion, splicing modulation, localization studies, and RNA imaging. This versatility makes Cas13 an important conceptual bridge between genome editing and transcript engineering, showing that CRISPR principles can be translated into RNA space without relying on DNA cleavage (Cox et al., 2017; Xu et al., 2021; Yang & Patel, 2024).

For therapeutic purposes, Cas13-based systems offer several advantages. The guide rules are intuitive, target choice can be highly flexible, and transcript-specific intervention may help distinguish pathogenic isoforms from beneficial ones. However, RNA targeting also introduces distinctive concerns. Some Cas13 proteins display collateral RNA cleavage in certain contexts, and even when collateral effects are minimized, prolonged expression may alter endogenous RNA surveillance pathways or innate immune sensing. Engineering efforts therefore focus on protein selection, catalytic tuning, guide design, and delivery format to preserve the strengths of RNA targeting while avoiding global transcriptome disruption.

The broader significance of Cas13 is that it opens a continuum of RNA interventions. A researcher may silence a transcript, recruit an editor, manipulate a splice decision, or track RNA localization using related molecular logic. In this way, Cas13 helps define the post-CRISPR era not simply as a set of replacement editors, but as a toolkit of specialized programmable biomolecular functions.

RNA editing

Clinical opportunities, dosing logic, and practical limits

The reversibility of RNA editing is often described as a safety feature, but it is equally a pharmacological feature. Because edited transcripts decay, therapeutic effect depends on expression kinetics, redosing schedule, and tissue turnover. This property may be advantageous for diseases in which the treatment window is episodic, developmental timing matters, or long-term constitutive editing could become harmful. Neurological disorders, inflammatory conditions, and some retinal diseases are frequently discussed in this context because transient adjustment of a transcript or protein may be clinically meaningful even if genomic correction remains out of reach (Booth et al., 2023; Khosravi & Jantsch, 2021; Yu et al., 2024).

Yet reversibility also imposes practical constraints. Chronic dosing may be necessary, delivery vehicles must be compatible with repeat administration, and therapeutic thresholds may fluctuate with transcript abundance. RNA editing may therefore resemble biologic therapy more than one-time gene correction in certain indications. This changes how efficacy should be measured: durable clinical benefit may still be possible, but it may depend on treatment schedules rather than permanent molecular conversion. Regulatory evaluation will likewise need to consider both editing specificity and exposure management over time.

The future clinical role of RNA editing will probably be defined by fit-for-purpose use cases. It is unlikely to replace permanent DNA correction where a single durable intervention is feasible and safe. Instead, it may excel where precision, reversibility, isoform selectivity, or tissue constraints make transcriptome targeting the more rational therapeutic choice.

Programmable integration

Why large-payload insertion is a distinct engineering problem

Correcting a point mutation and installing an intact therapeutic cassette are fundamentally different problems. Small edits can often be written locally, but large-sequence insertion requires precise handling of extensive DNA payloads, maintenance of orientation, and protection from rearrangement or truncation. Classical homology-directed knock-in strategies can achieve these goals, yet efficiency is often low and strongly dependent on cell state. Nondividing cells are especially challenging, and donor-template management adds additional complexity. For this reason, programmable integration has emerged as a separate frontier within the post-CRISPR landscape rather than as a mere extension of standard editing workflows (Wang et al., 2023; Chen et al., 2024; Yarnall et al., 2023).

The appeal of programmable integration is obvious. Many therapeutic and synthetic-biology applications require the addition of more than a few corrected bases. Researchers may need to insert full-length cDNAs, regulatory elements, biosensors, landing pads, recombinase targets, or multiplexed genetic circuits. These applications demand systems that can move beyond repair-template reliance and deliver larger genetic information in a controlled, site-specific way. Importantly, the desired insertion site may be chosen for safety, expression stability, or chromatin accessibility rather than because it contains a disease-causing mutation. Large-payload insertion therefore expands gene editing from repair toward genomic programming.

In practical terms, programmable integration is central to next-generation cell therapy, synthetic biology, and durable gene replacement. A field that can only cut or make small edits remains limited. A field that can place sizable functional modules at defined loci begins to resemble a true genomic engineering discipline.

Programmable integration

PASTE and integrase-coupled insertion strategies

PASTE exemplifies the idea that targeted integration can be decomposed into specialized steps. Rather than depending on double-strand-break repair, the system couples programmable targeting with reverse transcription and serine integrase function so that a genomic landing sequence can be installed and then used to mediate cargo insertion. The conceptual importance of this design is substantial. It treats targeted insertion not as an accidental outcome of cellular repair, but as an orchestrated sequence of enzymatic actions in which recognition, writing, and integration are distributed across modules with distinct roles (Yarnall et al., 2023; Hosur et al., 2022).

This modularity creates several benefits. Large cargo insertion becomes less dependent on homology-directed repair, the insertion step can be more explicitly controlled, and the design can in principle be adapted to different payload sizes or genomic contexts. It also offers a path toward cleaner engineering logic: first specify where the genome should accept a payload, then use an integration chemistry optimized for that task. For therapeutic development, that separation is attractive because it allows each step to be measured, improved, and regulated independently. It may also support safer installation of cassettes at predefined genomic sites that are selected for expression stability and minimized disruption of endogenous genes.

Challenges remain, including total cargo handling, delivery complexity, and the need to characterize rare rearrangements or partial integrations. Nevertheless, integrase-coupled strategies illustrate a broader trend in post-CRISPR engineering: the most difficult tasks are increasingly solved by combining multiple molecular functions rather than expecting one nuclease to do everything.

Programmable integration

CRISPR-associated transposons and related insertion systems

CRISPR-associated transposon systems offer another route to programmable integration by linking guide-directed targeting to transposition machinery. In contrast to repair-template-dependent knock-in, these systems draw inspiration from naturally mobile genetic elements that can move DNA cargo with their own enzymatic logic. Their emergence has energized the field because they suggest that insertion can be encoded as a native biological process rather than as a forced outcome of host repair. If sufficiently refined, such systems could provide robust ways to install larger sequences in contexts where homologous recombination performs poorly (Hsieh & Peters, 2024; Witte et al., 2025).

However, transposon-derived systems also raise distinctive design questions. Researchers must control target-site selection, insertion orientation, cargo boundaries, and genomic neighborhood effects. Some systems perform well in prokaryotic settings but require substantial adaptation for mammalian use. Others face challenges in cargo size, precision, or component complexity. Even so, CRISPR-associated transposons have already changed the conceptual landscape by demonstrating that programmable insertion is not limited to one molecular blueprint. They expand the menu of possible integration chemistries and encourage parallel exploration of multiple insertion paradigms.

For review authors, the key point is not that one platform has already solved all insertion challenges, but that the problem has moved into a tractable engineering domain. Large-payload insertion is now being approached with integrases, transposases, landing-pad strategies, and hybrid systems. This plurality will likely persist, with different insertion tools maturing for different tissues, cargo sizes, and translational constraints.

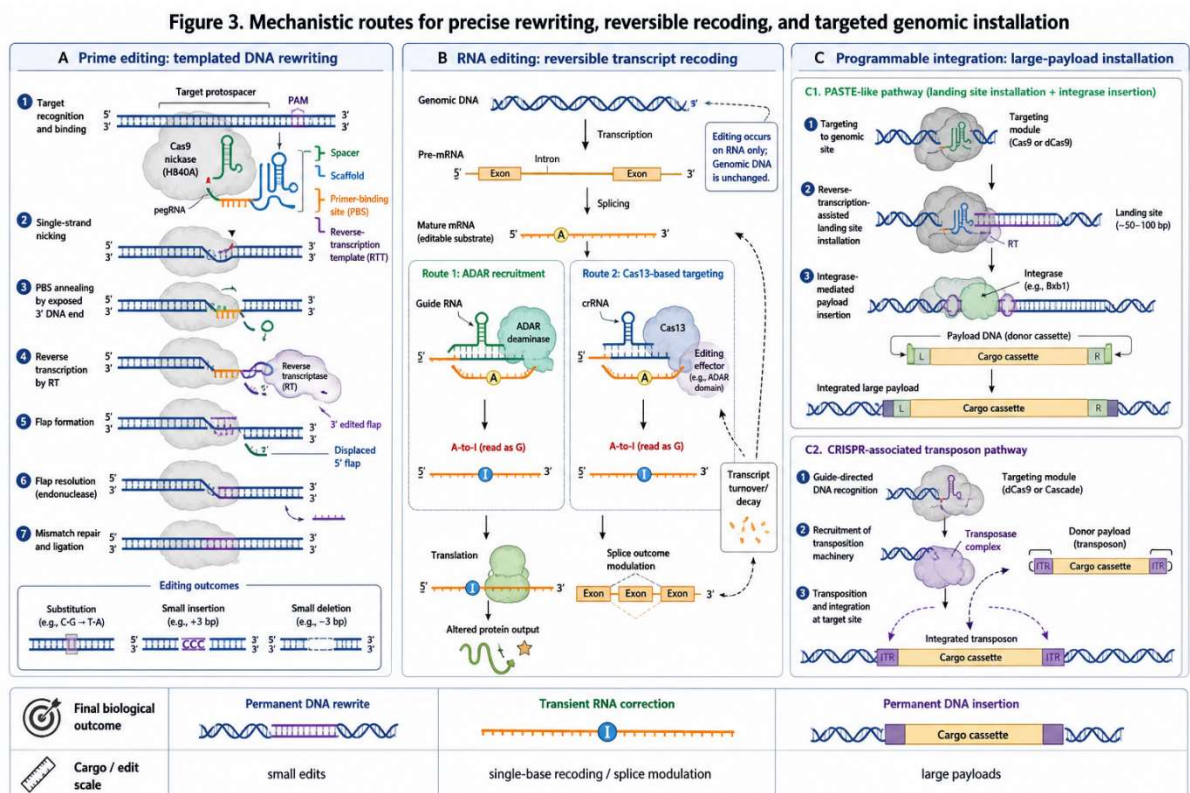


Figure 3 illustrates three mechanistically distinct post-CRISPR editing routes. In prime editing, a Cas9 nickase–reverse transcriptase complex uses a pegRNA containing a spacer, primer-binding site (PBS), and reverse-transcription template (RTT) to install defined sequence changes after single-strand nicking, primer annealing, reverse transcription, flap resolution, and mismatch repair. In RNA editing, programmable ADAR- or Cas13-based systems target RNA rather than DNA,

enabling reversible transcript recoding through adenosine-to-inosine conversion, altered protein output or splice behavior, and natural signal loss through RNA turnover. In programmable integration, the figure depicts both a PASTE-like route, in which a landing site is installed and then used for serine integrase-mediated cargo insertion, and a CRISPR-associated transposon route, in which guide-directed transposition machinery inserts a larger DNA payload into a defined genomic locus. The bottom comparison strip distinguishes permanent DNA rewriting, transient RNA correction, and permanent large-payload DNA insertion.

Comparative perspective

Choosing among prime editing, RNA editing, and programmable integration

The post-CRISPR toolkit should not be evaluated as a competition with a single winner. Each platform is optimized for a different class of biological problem. Prime editing is strongest when the goal is to install defined small sequence changes in DNA. RNA editing is most compelling when reversible, transcript-specific correction is preferred. Programmable integration becomes essential when therapeutic benefit depends on delivering large genetic payloads or durable synthetic modules. Selecting the appropriate tool therefore begins with a clear statement of the desired biological outcome rather than with loyalty to a particular molecular technology (Chen & Liu, 2023; Booth et al., 2023; Wang et al., 2023).

This comparative view also changes how success is measured. For prime editing, efficiency and product purity at nucleotide resolution are central. For RNA editing, duration, redosing logic, isoform specificity, and transcriptome-wide selectivity may be equally important. For programmable integration, cargo integrity, site specificity, copy number control, and long-term expression stability become defining parameters. A platform that appears inferior by one metric may still be superior for the intended indication because the therapeutic question itself is different. Precision medicine will likely depend on matching editor class to disease architecture rather than forcing all diseases into one editing template.

The most mature translational pipelines may ultimately combine these tools. A program might use prime editing to repair a pathogenic allele *ex vivo*, RNA editing to fine-tune a dosage-sensitive pathway during development, and programmable integration to install durable regulatory modules in engineered cell products. The post-CRISPR era is therefore best understood as an expansion of options that enables more rational intervention design.

Safety and specificity

Off-target activity, cellular stress, and immune recognition

Every editing platform introduces a characteristic safety profile, and those profiles are not interchangeable. Prime editing reduces some risks associated with double-strand breaks, yet it can still produce unintended edits, indels, or low-frequency by-products depending on pegRNA design and repair context. RNA editing avoids permanent DNA alteration, but it must contend with transcriptome-wide selectivity, guide-dependent misediting, and repeated exposure. Programmable integration promises durable installation of larger cargos, but it also demands rigorous assessment of insertion fidelity, payload integrity, and rare structural outcomes. Safety review in the post-CRISPR era therefore requires platform-specific rather than generic thinking (Bennett et al., 2020; Yu et al., 2020; Masarwy et al., 2024).

Cellular responses add another layer of complexity. Exogenous proteins, guide RNAs, delivery vehicles, and nucleic-acid intermediates can activate innate immune pathways or stress responses. Even when target editing is accurate, inflammatory signaling or growth disadvantage in edited cells may shape the eventual outcome. Long-lived tissues raise further questions about persistence, clonal selection, and surveillance. Consequently, preclinical development increasingly depends on orthogonal assays that measure not only editing at the intended locus but also transcriptional perturbation, chromosomal integrity, immunogenicity, and functional cell state after editing.

A mature safety framework should therefore combine mechanism-aware design with layered monitoring. The aim is not simply to detect problems after they occur, but to choose editor architectures and delivery schedules that make problematic outcomes less likely from the outset. Such thinking will be essential if post-CRISPR tools are to move from powerful demonstrations to dependable clinical products.

Translation and regulation

Manufacturing, quality control, and clinical development

The translational bottleneck for advanced editors is not only whether they work, but whether they can be manufactured, characterized, and deployed reproducibly. Prime editors, RNA editors, and programmable integration systems often require large proteins, structured RNAs, multipart delivery formulations, or donor cargos that complicate production. Clinical development will therefore depend on scalable manufacturing processes for nucleic acids, viral systems, nanoparticles, and ex vivo cell products, together with release assays that reflect true biological function rather than simple component abundance (Herrera-Barrera et al., 2023; Masarwy et al., 2024; Witte et al., 2025).

Quality control becomes especially demanding when the editor itself is modular. It may be necessary to characterize guide integrity, protein purity, formulation stability, packaging heterogeneity, and batch-to-batch consistency while also demonstrating locus-level editing performance in relevant cells. Regulators will likely expect evidence that critical quality attributes are linked to clinically meaningful outcomes, including editing precision, absence of major structural abnormalities, and predictable durability of effect. As more programs enter development, standardization of analytical pipelines will become as important as innovation in editor chemistry.

Regulatory frameworks may evolve differently for permanent and reversible platforms. A one-time genomic intervention invites long-term follow-up centered on durability and late-emerging risk, whereas a repeat-dose RNA-editing therapy may resemble advanced pharmacology with cumulative exposure management. Successful translation will therefore require not just better editors, but clearer regulatory logic tailored to the biological permanence of each platform.

Applications beyond therapy

Functional genomics, synthetic biology, agriculture, and biotechnology

Although therapeutic gene correction is the most visible driver of post-CRISPR innovation, these tools are equally important outside clinical medicine. In functional genomics, prime editing enables precise saturation mutagenesis and cleaner causal testing of coding and regulatory variants. RNA editing can transiently perturb transcripts to study timing-sensitive processes, dosage effects, and isoform-specific biology. Programmable integration supports the installation of reporters, barcodes, landing pads, and synthetic circuits that make cellular systems more measurable and more engineerable. Together, these methods increase the experimental resolution with which genotype can be linked to phenotype (Rees & Liu, 2018; Gaudelli et al., 2017; Adikusuma et al., 2021).

In synthetic biology, programmable integration is particularly transformative because it allows researchers to build durable genetic logic into cells. Engineered immune cells, microbial chassis, or stem-cell-derived models may all benefit from defined insertion of sensing modules, memory circuits, or therapeutic payloads at locations chosen for predictable expression. Prime editing complements these efforts by refining circuit components or tuning regulatory elements without disturbing the broader construct architecture. RNA editing, meanwhile, offers an appealing control layer for reversible, state-dependent modulation of engineered programs (Yarnall et al., 2023; Hsieh & Peters, 2024).

Agriculture and industrial biotechnology also stand to benefit. Crop traits often involve complex combinations of promoter variants, coding changes, and transgene insertion needs that

cannot be addressed by one editing mode alone. Post-CRISPR platforms therefore broaden the design space for trait stacking, stress tolerance, metabolic optimization, and precision breeding while offering new ways to balance durability, regulatory acceptance, and trait specificity.

Future directions

Convergence, smarter design, and next-generation precision medicine

A defining feature of the next phase of genome engineering will likely be convergence. Prime editing, RNA editing, and programmable integration are often presented as separate technologies, yet future therapeutic systems may combine their logic in staged or layered interventions. A patient-specific treatment could use one platform to install a landing site, another to tune expression during a vulnerable developmental window, and a third to maintain long-term correction with minimal genomic disruption. The more these tools mature, the more treatment design will resemble systems engineering rather than single-enzyme deployment (Lee et al., 2025; Zeng et al., 2024; Yang & Patel, 2024; Witte et al., 2025).

Computational design will also become increasingly central. Predictive models for pegRNA performance, RNA accessibility, integration outcomes, chromatin context, and immunogenicity can shorten development cycles and reduce empirical trial-and-error. Machine learning will not replace molecular experimentation, but it can prioritize better candidates, reveal hidden determinants of success, and help match editor architectures to tissue- and disease-specific constraints. In that sense, the future of post-CRISPR engineering lies as much in design intelligence as in protein evolution.

Ultimately, the significance of the post-CRISPR toolkit is strategic. It frees precision medicine from the assumption that every genetic problem should be solved by cutting DNA. Instead, researchers can choose among rewriting, reversible transcript correction, and guided installation of larger payloads. This expanded repertoire is likely to define the next generation of functional genomics and gene therapy.

Conclusion

From gene cutting to programmable biological control

The post-CRISPR toolkit marks a transition from first-generation editing, which was dominated by programmable cleavage, to a broader era of programmable biological control. Prime editing offers a route to precise sequence rewriting without conventional double-strand-break dependence. RNA editing brings reversible transcript correction into the therapeutic and experimental mainstream. Programmable integration addresses the long-standing challenge of targeted installation of larger genetic payloads. Each platform solves a different problem, and together they transform what investigators can reasonably attempt in genome engineering (Anzalone et al., 2019; Cox et al., 2017; Yarnall et al., 2023).

This transition is important not only because the tools are more sophisticated, but because they encourage more disciplined matching of molecular mechanism to biological objective. The central question is no longer whether CRISPR can cut at a site of interest. It is whether a given disease, cell type, developmental window, and therapeutic objective are best served by permanent genomic rewriting, transient transcript correction, or site-specific genetic installation. That shift in framing is what makes the post-CRISPR era qualitatively different from the one that preceded it.

As delivery methods improve, analytical standards mature, and regulatory experience accumulates, the tools discussed in this review are likely to move from emerging platforms to foundational modalities. Their long-term impact will be measured by how effectively they enable safer, more precise, and more adaptable interventions across medicine, agriculture, and biotechnology.

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БАУЫРМЕН ЖОРҒАЛАУШЫЛАРДЫҢ ПАРК АУМАҒЫНДА ТАРАЛУ ЕРЕКШЕЛІГІ

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Мақалада Сырдария-Түркістан мемлекеттік өңірлік табиғи паркінің аумағында таралған бауырымен жорғалаушылардың түрлік құрамы мен таралу ерекшеліктері қарастырылған. Парк аумағының табиғи-климаттық жағдайлары, ландшафттық ерекшеліктері және олардың бауырымен жорғалаушылардың тіршілік етуіне әсері сипатталған. Зерттеу барысында шөлейт, өзен жайылмасы және таулы аймақтарда кездесетін негізгі түрлер анықталып, олардың таралуына ықпал ететін экологиялық факторлар талданды. Сонымен қатар бауырымен жорғалаушыларды қорғау мен сақтау шараларының маңыздылығы көрсетілді. Зерттеу нәтижелері парк аумағындағы биоалуантүрлілікті сақтау және табиғи экожүйелердің тұрақтылығын қамтамасыз ету үшін ғылыми негіз бола алады.

Түйін сөздер: *бауырымен жорғалаушылар, биоалуантүрлілік, Сырдария-Түркістан мемлекеттік өңірлік табиғи паркі, экожүйе, таралу ерекшелігі, герпетофауна, табиғатты қорғау.*

Қазақстан аумағындағы ерекше қорғалатын табиғи аймақтар биоалуантүрлілікті сақтауда маңызды рөл атқарады. Соның ішінде Сырдария-Түркістан мемлекеттік өңірлік табиғи паркі Түркістан облысының табиғи экожүйелерін қорғауға бағытталған ірі табиғи аумақтардың бірі болып табылады. Парк аумағы Сырдария өзенінің жайылмаларын, шөлейт және таулы ландшафттарды қамтиды. Бұл аймақтар бауырымен жорғалаушылардың көптеген түрлерінің тіршілік етуіне қолайлы орта қалыптастырады.

Бауырымен жорғалаушылар – қоршаған орта жағдайына өте сезімтал омыртқалы жануарлар тобы. Олардың таралуы климаттық жағдайларға, топырақ құрамына, өсімдік жамылғысына және су көздерінің болуына тікелей байланысты. Сондықтан парк аумағындағы бауырымен жорғалаушылардың таралу ерекшеліктерін зерттеу табиғи экожүйелердің жағдайын бағалауда маңызды ғылыми негіз болып саналады.

Парк аумағының табиғи ерекшеліктері

Сырдария-Түркістан мемлекеттік өңірлік табиғи паркі 2012 жылы құрылған. Парк құрамына Түркістан, Сырдария және Боралдай филиалдары кіреді. Жалпы аумағы шамамен 120 мың гектардан асады. Парк аумағында өзен аңғарлары, тоғайлы ормандар, құмды және сазды шөлейттер, сондай-ақ аласа таулы аймақтар кездеседі.

Аймақтың климаты шұғыл континенттік, жазы ыстық әрі құрғақ, қысы салыстырмалы жұмсақ болып келеді. Мұндай климаттық жағдайлар бауырымен жорғалаушылардың белсенді тіршілігіне қолайлы орта қалыптастырады. Әсіресе көктем мен жаз мезгілдерінде олардың белсенділігі жоғары болады.

Бауырымен жорғалаушылардың таралу ерекшеліктері

Парк аумағында бауырымен жорғалаушылардың әртүрлі экологиялық топтары таралған. Оларға кесірткелер, жыландар және тасбақалар жатады. Бұл жануарлардың таралуы табиғи ортаның ерекшелігіне қарай өзгереді.

1. Шөлейт және құмды аумақтар

Парктың шөлейт аймақтарында ағамалар, сұр кесірткелер және әртүрлі жылан түрлері кең таралған. Құмды жерлер күн сәулесін жақсы сақтайтындықтан, суыққанды жануарлардың дене температурасын реттеуіне мүмкіндік береді. Сонымен қатар сирек өсімдік жамылғысы олардың қозғалуына қолайлы жағдай жасайды.

2. Өзен жайылмалары мен тоғайлы аймақтар

Сырдария өзенінің жағалауы мен тоғайлы алқаптарында ылғалсүйгіш бауырымен жорғалаушылар көбірек кездеседі. Бұл аумақтарда су жыландары мен кейбір қосмекенділерге жақын тіршілік ететін түрлер таралған. Өзен маңындағы қалың өсімдіктер оларды жыртқыштардан қорғайды және қорек қорын қамтамасыз етеді.

3. Таулы және тасты аймақтар

Боралдай жоталары мен тастақты өңірлерде жартасты мекендейтін кесірткелер жиі кездеседі. Тасты жерлер күннің жылуын ұзақ сақтайды, сондықтан бұл аймақтар бауырымен жорғалаушылар үшін тиімді мекен ортасы болып табылады.

Таралуына әсер ететін факторлар

Бауырымен жорғалаушылардың парк аумағында таралуына бірнеше экологиялық фактор әсер етеді:

- ауа температурасы;
- ылғал мөлшері;
- өсімдік жамылғысының тығыздығы;
- су көздерінің болуы;
- антропогендік әсер;
- қоректік базаның жеткіліктілігі.

Соңғы жылдары экотуризмнің дамуы мен адам әрекетінің артуы кейбір түрлердің таралу аймағына кері әсер етуі мүмкін екендігі айтылуда.

Қорғау және сақтау шаралары

Парк аумағында биоалуантүрлілікті сақтау мақсатында табиғатты қорғау іс-шаралары жүргізіледі. Ерекше қорғалатын табиғи аумақ режимі сирек кездесетін жануарларды қорғауға мүмкіндік береді. Сонымен қатар ғылыми мониторинг жұмыстары жүргізіліп, жануарлар дүниесінің маусымдық өзгерістері бақыланады.

Бауырымен жорғалаушылар экожүйедегі маңызды буын болып табылады. Олар жәндіктер мен кеміргіштердің санын реттеуге қатысады және көптеген жыртқыш жануарлар үшін қорек көзі саналады. Сондықтан оларды қорғау табиғи тепе-теңдікті сақтауда маңызды рөл атқарады.

Бауырмен жорғалаушылардың түрлері

Парк аумағында кездесетін бауырымен жорғалаушылардың негізгі түрлері:

- келес кесірткесі
- сұр кесіртке
- агама
- Орта Азия тасбақасы
- өрнекті қарашұбар жылан
- сарыбас жылан
- оқжылан
- су жыланы, гюрза (кей аумақтарда кездесуі мүмкін).



Сурет 1. Келес кесеткесі

Келес – ірі кесірткелердің бірі. Денесінің ұзындығы құйрығымен бірге 1 метрге дейін жетеді. Құмды және шөлейт жерлерде тіршілік етеді. Жәндіктермен, ұсақ кеміргіштермен қоректенеді. Парк экожүйесінде зиянкестер санын реттеуге көмектеседі.



Сурет 2. Өрнекті қарашұбар жылан

Бұл улы емес жылан түрі. Денесінде қара дақты өрнектері болады. Көбінесе өзен маңы мен шөптесін жерлерде кездеседі. Ұсақ кеміргіштермен және кесірткелермен қоректенеді.



Сурет 3. Орта Азия тасбақасы

Шөл және шөлейт аймақтарға бейімделген тасбақа түрі. Қабығы қатты әрі дөңгелек пішінді келеді. Негізінен өсімдіктермен қоректенеді. Көктемде белсенді болып, жаздың қатты ыстығында інге тығылып жатады.

Қорытынды

Қорыта айтқанда, Сырдария-Түркістан мемлекеттік өңірлік табиғи паркі аумағы бауырымен жорғалаушылардың таралуына қолайлы табиғи кешендердің бірі болып табылады. Парктағы әртүрлі ландшафттық аймақтар көптеген түрлердің тіршілік етуіне мүмкіндік береді. Олардың таралу ерекшеліктері климаттық және экологиялық жағдайлармен тығыз байланысты. Бауырымен жорғалаушыларды зерттеу мен қорғау парк экожүйесінің тұрақтылығын сақтауға және биоалуантүрлілікті қорғауға маңызды үлес қосады.

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Agricultural Sciences

Results of hybridization of common proso millet based on crossbreeding of local and foreign varieties

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Introduction. Proso millet (*Panicum miliaceum* L.) is one of the oldest crops used by humans as food. It is a cereal plant belonging to the Poaceae family [1].

The origins of proso millet are linked to the early stages of agriculture. Proso millet was first cultivated approximately 7,000 years ago in China and the Caucasus [2]. Proso millet was an important element of ancient civilizations such as the Egyptian and Mediterranean [3]. In ancient times, it was widely used as a primary food source for many peoples. The process of proso millet domestication represents an evolutionary process through which the wild species of proso millet (became cultivated and grown by humans to meet their nutritional needs) began to be cultivated.

The history of proso millet domestication can be divided into the following stages [4]:

- Selecting and collecting wild species: Ancient hunting and gathering societies began to notice wild proso millet plants in their surroundings. Over time, they may have realized that the seeds were edible.

- Selection: Humans began collecting seeds with the best characteristics, such as disease resistance, high yield, and other beneficial properties. This selection process led to the development of different proso millet varieties more suitable for cultivation.

- Cultivation: With the development of agriculture, people began systematically growing proso millet in their fields. This stage included choosing a planting site, applying fertilizers, watering, and other methods to ensure a high yield.

- Use in everyday life: The successive stages of proso millet domestication have led to this plant becoming an important food source in everyday life. The production of proso millet products such as porridge, bread, and cereals, as well as its use in brewing, have made it an integral part of the diet of many societies.

Proso millet is an annual plant with slender stems and linear leaves [5]. Proso millet grains are round or oval in shape and are highly resistant to extreme climatic conditions. The plant can adapt to various soil types, making it a valuable crop [6]. Stem height varies depending on the variety and growing conditions, but typically ranges from 50 cm to 1 meter. The stems are covered with narrow linear leaves. Proso millet leaves are linear, narrow, with a floating vein structure. They are arranged along the stem, creating a green, pinnate plant. Proso millet root is a short system that provides the plant with moisture and nutrients. Flowers can have various shades, such

as green, red, or purple. Proso millet's primary agricultural value is in its grains: round or oval, they can be white, yellow, or red, depending on the variety. They are rich in a variety of nutrients. Proso millet grains are rich in carbohydrates, fiber, and protein. They also contain B vitamins, iron, magnesium, and other minerals. This makes proso millet a valuable source of energy and nutrients for humans. It's also worth noting that proso millet is virtually gluten-free, making it a recommended food for people with celiac disease, a congenital disease that is caused by intolerance to the protein of certain cereal crops [7].

Proso millet has a wide range of culinary uses. It is used to make porridge, flour, bread, and other products. Proso millet is also used in the production of beverages such as beer.

Proso millet grains are considered a good fodder for poultry and livestock. Waste from the grain processing process is also used as livestock feed.

The importance of proso millet is difficult to overestimate. This plant is an important food source for many countries, especially in regions with unfavorable agricultural conditions. Due to its high adaptability, proso millet has become an important human cereal, capable of growing in a variety of agroclimatic zones, which is extremely relevant for the Republic of Kazakhstan with its arid climate [8]. Proso millet can be sown late, at different periods. Moreover, few seeds are required per unit of area. Proso millet is drought-resistant. Even in the driest years, proso millet yields 12-15 centners of harvest per hectare, and the average yield reaches 25-38 centners. It is easy to store and transport.

In 2020, the proso millet sown area in Kazakhstan amounted to 52,868.8 hectares. More than half of this area was located in the Pavlodar region (27,973.6 hectares). Kostanay (9,267 hectares) and Aktobe regions (5,742 hectares) also ranked among the top three regions in terms of sown and harvested proso millet areas. Currently, 22 proso millet varieties for grain and 13 for feed have been approved for production in Kazakhstan. Varieties such as Barnaulskoye 98, Omskoye 11, Saratovskoye 6, Shortandinskoye 6, Shortandinskoye 11, and Yarkoye 6 are dual-purpose varieties suitable for both grain production and feed (green mass and hay) [8].

Proso millet (*Panicum miliaceum* L.) is one of the most drought-tolerant crops used in agriculture for grain production [10]. It has several characteristics that make it quite drought-resistant and adapted to cultivation in conditions of limited access to water:

- deep roots: Proso millet plants have the ability to develop a deep root system, which helps them extract water from deeper soil layers. This allows the plant to survive and continue to grow and develop during periods of drought.

- low water consumption: Like other cereals, proso millet is characterized by low water consumption, which means that it requires relatively less water for its growth and development compared to some other crops.

- short growing season: Proso millet has a relatively short growing season, meaning it's more adaptable to growing in areas with limited water availability. This allows it to be used in regions with short rainy seasons or harsh climates.

- ability to cope with periods without precipitation: in many regions where proso millet is traditionally cultivated, periods without precipitations are not uncommon, and the crop copes successfully with such conditions due to its drought resistance.

However, it must be remembered that although proso millet has some degree of drought tolerance, its yield can still be highly dependent on water availability and other agronomic factors such as soil fertility and agronomic practices [11].

Materials and Methods. For proso millet hybridization, seeds of 15 varieties were sown in pots, 15 seeds per variety, with two duplicates. Hybridization was carried out throughout the flowering phase, in July–August 2024.

Hybridization is an effective method for obtaining heterogeneous material for subsequent selection and creation of varieties [12]. Proso millet is a self-pollinating plant. Currently, the

following basic characteristics of proso millet flowering biology are adhered to during hybridization: all normally developed and undamaged flowers bloom openly. Physiologically ready for flowering buds that did not open due to unfavorable conditions bloom in the following days, when optimal conditions arise. Based on a study of the biology of flowering and pollination of proso millet, it was proposed to castrate proso millet flowers at the moment when the spikelet and floral films of the flower open for flowering, and the anthers begin to release the stigma, tightly adhering to them. Before starting hybridization, it should be taken into account that the paternal plants should bloom 2-3 days earlier than the maternal plants. Hybridization of proso millet should begin on the 2-3rd day after the onset of flowering, when the upper and middle parts of the panicle have bloomed. The best time to castrate flowers is during the intense flowering period of proso millet, from 8 a.m. to 11 or 12 p.m. Pollination of the flower must be carried out very carefully to avoid damaging the stigma. After 3-4 days, the insulator is removed. The plant is labeled, indicating the crossbreeding combination, date, and time of pollination [13]. After reaching maturity, the percentage of grain formation is calculated based on the number of grains formed.

Obtaining hybrid seeds in the field is time-consuming, and seed setting is dependent on environmental conditions, complicating the pollination process due to the unique flowering biology of proso millet. Conducting hybridization under controlled conditions increases the efficiency of hybrid population production, thereby optimizing the breeding process regardless of the conditions and location of the experiment. To synchronize flowering times, selected parental forms with varying precocity were sown in pots on May 5, 15, and 25, taking into account the predicted dates of flowering. For hybridization, 22 parental pairs of different origins were selected and placed in pots at different times, taking into account the growing season of each genotype.

Results. As a result of hybridization, out of all the combinations carried out (Table 1), 22 were successful. A total of 908 pistils were pollinated and 175 hybrid grains were obtained, while the percentage of setting was on average 18.4 %.

Table 1 - Results of successful hybridization of proso millet varieties and samples

Combinations	Number of castrated and pollinated flowers, pcs.	Number of set seeds, pcs	Success rate, %
♀PI 211058×♂Shortandinskoe 7	45	12	26.6
♀PI 211058×♂Uralskoe 109	48	4	8.3
♀K-3906×♂Saratovskoe 6	31	4	12.9
♀Yarkoe 6×♂PI 211058	48	33	68.7
♀Shortandinskoe 7×♂K-1474	42	16	38.10
♀PI 211058×♂Uralskoe 109	47	7	14.89
♀PI 209790×♂Yarkoe 6	36	6	16.67
♀K-3906×♂Saratovskoe 6	40	4	10.0
♀K-2241×♂Shortandinskoe 7	40	2	5.00
♀K-2241×♂K-3906	40	12	30.0
♀K-3906×♂Shortandinskoe 7	40	3	7.5
♀Shortandinskoe 7×♂K-3906	40	1	2.5
♀K-2468×♂Shortandinskoe 7	50	18	36.0
♀PI 209790×♂K-2241	51	7	13.7
♀K-2241×♂PI 209790	46	7	15.2
♀K-2274×♂K-2241	52	14	26.9
♀K-2274×♂PI 175798	38	6	15.7
♀Shortandinskoe 7×♂K-2274	35	8	22.8
♀Shortandinskoe 7×♂PI 175798	30	4	13.3
♀PI 175798×♂Shortandinskoe 7	46	4	8.7
♀Shortandinskoe 7×♂PI 177015	17	1	5.8
♀PI 177481×♂Yarkoe yubileynoe	46	2	4.3
Total	908	175	18.4

High success rate was achieved by crossing local varieties with foreign samples. Thus, the combinations ♀Shortandinskoe 7 × ♂K-2274; ♀PI211058 × ♂Shortandinskoe 7; ♀K-2468 × ♂Shortandinskoe 7; ♀Shortandinskoe 7 × ♂K-1474 and ♀Yarkoe 6 × ♂PI 211058 had fruit set rates of 38.10%, 22.86%, 26.6%, 36.0% and 68.7%, respectively. When hybridizing the collection samples K-2241 and K-3906, it was also possible to obtain 12 hybrid grains from 40 castrated flowers; the percentage of fruit set in this combination was 30.0%.

Forced hybridization of domestic and foreign samples proved their high genetic compatibility: ♀PI 211058×♂Uralskoe 109 - 8.3%; ♀PI 175798×♂Shortandinskoe 7 - 8.7%; ♀K-3906×♂Saratovskoe 6 - 10.0%, ♀K-3906×♂Saratovskoe - 12.9%; PI 209790×♂K-2241 - 13.73%, ♀Shortandinskoe 7 ×♂PI 175798 - 13.33%; ♀PI 211058×♂Uralskoe 109 - 14.89%; ♀PI 209790×♂Yarkoe 6 - 16.67%, ♀K-2241×♂PI 209790 - 15.22%; ♀K-2274×♂PI 175798 - 15.79%. The lowest percentage of fruit set was found in the following combinations: ♀Shortandinskoe 7×♂K-3906 - 1 grain out of 40 castrated (2.50%); ♀PI 177481×♂Yarkoe yubileynoe - 2 grains out of 46 castrated (4.35%); ♀K-2241×♂Shortandinskoe 7 - 2 grains out of 40 castrated (5.0%);

♀ Shortandinskoe 7 × ♂ PI 177015 - 1 grain from 17 castrated flowers (5.88%) and ♀ K-3906 × ♂ Shortandinskoe 7 - 3 grains from 40 flowers (7.50%) were obtained.

For further phenological observations, hybrid seeds were sown in pots. As a result of phenological observations, a heterosis effect was observed in the F₁ generation (Figure 1).



Figure 1 - Hybrid combinations of F₁ generations with parental forms

Conclusion. Overall, the analysis of hybrid grains revealed that 22 of 43 combinations were successful. The seed set rate in the crosses ranged from 2.5% to 68.7%, with an average of 18.4 %. However, given the biological characteristics of proso millet, each grain has high genetic potential, making it possible to obtain a sufficient number of seeds for hybrid analysis and an assessment of the potential of this crop.

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Comparative assessment of valuable agronomic traits of the Chinese collection of common buckwheat samples in the conditions of the Akmola region

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Introduction. Buckwheat is a leading cereal crop, possessing high nutritional and dietary value. The grain is used to produce cereals and flour and is rich in easily digestible proteins, B vitamins, trace elements, and rutin, which is beneficial for strengthening blood vessels. Due to its gluten-free nature, buckwheat is valued in medicinal and baby food [1].

Vegetative mass and by-products of grain processing are used in animal husbandry as nutritious feed [2].

Buckwheat plays an important agronomic role. By releasing organic acids, its root system helps convert poorly soluble phosphorus compounds into a more readily available form, improving soil fertility and making buckwheat a good precursor for many crops [3].

The primary center of buckwheat domestication is considered to be the interior regions of Southeast Asia (western China, Tibet, eastern India), where cultivation of its wild ancestors began around the sixth millennium BC. From this region, the crop spread to Central Asia, and subsequently to the Middle East and Europe. Archaeological and paleontological evidence indicates a wide geographic distribution of early cultivation: the oldest traces in Finland date back to 5300 BC, pollen samples in Japan to 4000 BC, and finds in China to 2600 BC. Possessing unique biological plasticity, buckwheat is recognized as the highest-altitude domesticated crop in the world, as evidenced by its successful cultivation on the Tibetan Plateau (Yunnan Province).

Large-scale cultivation of the crop continued in Siberia, India, Turkey, and Japan. Buckwheat only entered European agricultural circulation on a large scale in the 15th century,

reaching Italy and neighboring countries via the trade routes of the Black Sea basin. During the colonial era, Europeans brought the crop to North America.

Thanks to its high protein content, buckwheat has become a staple in the cuisines of many countries, creating distinctive gastronomic traditions. In East Asian countries (China, Japan), buckwheat flour mixed with wheat flour is predominantly used to make noodles (soba); in Korea, the production of starchy foods (memil flour) is well-developed; and in India, the production of unleavened flatbreads (chapatis) is prominent. In Eastern Europe, whole-grain dishes such as porridges and soups predominate.

Current understanding of buckwheat phylogeny is based on research conducted in the late 20th century. Analysis of the ranges of wild ancestors allows us to localize the centers of origin of the main cultivated species. For common buckwheat, this region is the northwestern part of Yunnan Province. In turn, the center of origin of Tartary buckwheat is associated with the northwest of Sichuan Province, which is confirmed by data on allozyme variability of proteins in wild populations. It should be noted that the species *F. cymosum*, despite its morphological similarity, is not considered a direct ancestor of cultivated forms. Data from molecular genetic analysis (study of chloroplast DNA and *isozyme* composition) indicate a significant phylogenetic distance between *F. cymosum* and *F. Esculentum* [4-6].

Buckwheat (*Fagopyrum esculentum* Buckwheat) takes a special place among cereal crops due to its multifaceted economic importance, which is manifested in the food, feed, agricultural, honey, medicinal and environmental spheres. As a pseudocereal crop, it provides the population with a high-quality dietary product – buckwheat groats, which have a balanced amino acid composition (high content of lysine, methionine, tryptophan), are gluten-free, and have an increased level of dietary fiber, resistant starch, prebiotic oligosaccharides, B vitamins (B1, B2, PP), rutin, flavonoids, and minerals (Fe, Mg, P, Zn, Cu). Buckwheat is characterized by high biological value (its protein quality is comparable to that of chicken eggs), good digestibility, a low glycemic index, and functional properties. It helps lower cholesterol, normalize metabolism, and prevent cardiovascular diseases, diabetes, and anemia. Buckwheat remains a strategic food in the diets of people in Kazakhstan and other CIS countries, especially during periods of fasting, for children and dietary nutrition, and in times of food security.

Buckwheat's medicinal value stems from its high rutin content (up to 2-3% in the leaves and flowers), which is used in pharmaceuticals to treat vascular diseases, hemorrhoids, and varicose veins. The green mass and straw are used as livestock feed (although in limited quantities due to the fagopyrin content) and as bedding.

In Kazakhstan (especially the Akmola region), buckwheat is important for diversifying grain production, increasing farm profitability, and increasing exports (Kazakhstan is among the world's top 10 producers). High profitability in favorable years is combined with low soil and technology requirements, making buckwheat attractive to farmers in a changing climate and resource-deficient environment [7-8].

Materials and methods. The study material consisted of common buckwheat (*Fagopyrum esculentum* Moench subsp.) from Chinese selection. The Shortandinskaya coarse-grained variety was used as the standard (Table 1).

Table 1 - Buckwheat varieties and origins

Varieties	Origin
Shortandinskaya coarse-grained st.	Kazakhstan
9978 (XN- 9978)	China
T1208 (XN- T1208)	China
T1211 (XN- T1211)	China
T1311 (XN- T1311)	China
T1925 (XN- T1925)	China
Southern Chinese	China
Chinese Domestic	China

Field trials were conducted according to the methodology of B. A. Dospekhov. Field research was conducted at the A. I. Barayev Scientific and Production Center for Grain Farming. The collection was sown manually in the third ten-day period of May. The plot area was 2 m². The plots were systematically spaced, with a standard Shortandinskaya coarse-grained variety planted as every tenth. Row spacing was 20 cm, plant spacing was 5 cm, and seed placement depth was 5 cm. The plots in the collection nursery were placed systematically.

Results. By results phenological observations showed that all varieties of Chinese selection differed significantly from the standard Shortandinskaya coarse-grained variety by growing season (Table 2):

Table 2 - Phenological observations varieties buckwheat

Name variety samples	shoots	branching	budding	flowering	fruit formation	ripening
Shortandinskaya coarse-grained st.	10.06	26.06	06.07	13.07	28.07	16.09
9978 (XN- 9978)	13.06	01.07	09.07	19.07	05.08	23.09
T1208 (XN- T1208)	13.06	01.07	09.07	19.07	05.08	23.09
T1211 (XN- T1211)	13.06	01.07	09.07	19.07	05.08	23.09
T1311 (XN- T1311)	13.06	01.07	09.07	19.07	05.08	23.09
T1925 (XN- T1925)	13.06	01.07	09.07	19.07	05.08	23.09
Southern Chinese	10.06	26.06	11.07	17.07	05.08	23.09
Chinese Domestic	10.06	26.06	11.07	17.07	05.08	23.09

Most of the studied samples belong to the mid-season group. It was found that the conditions of a particular year (for example, excess moisture in August 2024) significantly affect the duration of interphase periods and harvesting timing harvest. Seedlings for most varieties were recorded between June 10 and 13. For example, the Shortandinskaya coarse-grained variety and foreign samples (Southern Chinese, Chinese Domestic) give shoots 10 June, the samples 9978, T1208, T1211, T1311, T1925 a little later, on June 13. The branching phase begins for the first varieties already on June 26, for the remaining varieties on 1 July. The budding phase of Shortandinskaya coarse-grained begins on July 6. Flowering also begins earlier on 13 July. Fruit formation of Shortandinskaya coarse-grained was noted on 28 July, for the rest of variety samples on 5 August. The standard variety's ripening phase was recorded on September 16, and the total number of growing days (from germination to ripening) is 98 days. These data show that the

Shortandinskaya coarse-grained variety develops earlier, progressing more quickly through all the main phases: branching, budding, flowering, fruiting, and ripening. Other varieties, including experimental and foreign varieties, show a delay of almost 3-4 days during the branching and budding phases and a similar delay during flowering and fruiting.

Growing season for results phenological observations ranged from 98 to 105 days (Table 3).

Table 3 - Phenological observations of buckwheat

Name of variety samples	Growing season, days	Deviation from standard, +/-
Shortandinskaya coarse-grained st.	98	-
9978 (XN- 9978)	102	+4
T1208 (XN- T1208)	102	+4
T1211 (XN- T1211)	102	+4
T1311 (XN- T1311)	102	+4
T1925 (XN- T1925)	102	+4
Southern Chinese	105	+7
Chinese Domestic	105	+7

The table presents data on the length of the growing season for various cultivar samples based on phenological observations. The standard variety is "Shortandinskaya coarse-grained st.", which has a growing season of 98 days. This value is taken as the baseline, and deviations from this standard are indicated for the other varieties. The following genotypes—9978 (XN-9978), T1208 (XN-T1208), T1211 (XN-T1211), T1311 (XN-T1311), and T1925 (XN-T1925)—all have a growing season of 102 days, which is 4 days longer than the standard variety. The Southern Chinese and Chinese Domestic varieties demonstrate the longest growing season—105 days, which is 7 days longer than the standard.

Thus, all the studied samples, except for the standard one, are characterized by a longer growing season, varying from +4 to +7 days compared to the standard variety.

In the field experiments photosynthesis was determined using MINI-PAM-II device in phases germination, budding and flowering (Table 4).

Table 4 - Intensity of photosynthesis of buckwheat samples ($\mu\text{mol CO}_2 / \text{m}^2$)

Name of variety samples	Shoots	Budding	Bloom
Shortandinskaya coarse-grained st.	0.708	0.892	0.893
9978 (XN- 9978)	0.598	0.802	0.899
T1208 (XN- T1208)	0.789	0.900	0.865
T1211 (XN- T1211)	0.645	0.968	0.870
T1311 (XN- T1311)	0.664	0.804	0.936
T1925 (XN- T1925)	0.782	0.820	0.751
Southern Chinese	0.79	0.924	0.915
Chinese Domestic	0.751	0.928	0.942

Analysis of the photosynthetic rate in various buckwheat varieties, measured at key development stages, revealed specific dynamic changes in each genotype. During the seedling stage, the highest rates were demonstrated by T1211 (0.968), Chinese Domestic (0.928) and Southern Chinese (0.924), while the lowest intensity was observed in the sample 9978 (0.802). During the budding period, the values decreased for all studied varieties, while the maximum photosynthetic activity was maintained in T1208 (0.789) and Southern Chinese (0.79), and the minimum was in

9978 (0.598). By the flowering stage, most samples, with the exception of T1925, showed an increase in the intensity of photosynthesis. Thus, the dynamics of photosynthetic activity throughout ontogenesis is cultivar-specific, which may be related to their adaptive potential.

Biometric indicators are a set of measurements that quantitatively characterize the morphological and physiological characteristics of a plant. They allow one to assess growth rates, development levels, yield potential, and agronomic adaptability of the plant. The main characteristics were plant height, number of first-order branches, number of second-order branches, number of seeds per plant, seed weight per plant, weight of 1000 seeds.

For each indicator, average values for the varieties were calculated and their variable characteristics were taken into account. The study results (Table 5) show that there are some differences in the morphological characteristics of plants from Chinese varieties and the standard variety.

Table 5 - Structural analysis of common buckwheat, 2025

Name of variety samples	plant weight, g	plant height, cm	1st order branches, pcs	2nd order branches, pcs	number of grains per plant, pcs	weight of grains per plant, g	weight of 1000 seeds, g
Shortandinskaya coarse-grained st.	23.2	91.8	4.4	18.7	424.7	12.1	30
9978 (XN-9978)	48.1	104.4	4.2	16.4	294.9	7,815	26
T1208 (XN-T1208)	26.8	134.8	6	17	132.6	3.3	21
T1211 (XN-T1211)	37.22	106.5	4.9	14.7	209.5	6.26	30.5
T1311 (XN-T1311)	48.2	102.8	6.2	45.4	307.6	8.6	22.5
T1925 (XN-T1925)	60.7	108.4	4.4	24.9	143.1	4.25	23
Southern Chinese	17	86.5	4	29.1	31.4	0.73	20.5
Chinese Domestic	31.65	95.8	5.9	25.9	101.5	4.53	22.5

The largest vegetative mass was formed by the T1925 (XN-T1925) sample (60.7 g per plant), which is more than 2.5 times higher than the indicator of the shortest and weakest sample in terms of mass, Southern Chinese (17.0 g). High plant weight was also demonstrated by the samples 9978 (XN-9978) - 48.1 g and T1311 (XN-T1311) - 48.2 g. The local standard Shortandinskaya coarse-grained st. had an average plant weight of 23.2 g, which is typical for the varieties adapted to local conditions.

The tallest specimen was T1208 (XN-T1208) at 134.8 cm, which is 43 cm taller than the Shortandinskaya coarse-grained st. standard (91.8 cm). Tall specimens were also T1211 (106.5 cm) and T1311 (102.8 cm). The shortest plant height was formed by the Southern Chinese - 86.5 cm. Chinese Domestic variety occupied an intermediate position - 95.8 cm.

In terms of the number of first-order branches, samples T1311 (6.2 pcs.) and T1208 (6.0 pcs.) stood out, while for the standard Shortandinskaya coarse-grained st. this figure was 4.4 pcs. The greatest second-order branching was noted in sample T1311 - 45.4 pcs., which is almost 2.5 times higher than the standard value (18.7 pcs.). Chinese samples also had high second-order branching: Southern Chinese - 29.1 pcs, and Chinese Domestic - 25.9 pcs. The smallest second-order branching was observed in sample 9978-16.4 pcs.

The Shortandinskaya coarse-grained variety produced the largest number of grains from one plant - 424.7 pcs. This significantly exceeded the other varieties. High values of this indicator were also noted for the samples T1311 (307.6 pieces) and 9978 (XN-9978) - 294.9 pieces. The lowest number of grains per plant was observed for the sample Southern Chinese - only 31.4 pieces, which is 13.5 times less than the standard. Chinese Domestic sample produced 101.5 grains per plant.

In terms of grain weight per plant, the Shortandinskaya coarse-grained st. standard was also the leader - 12.1 g. A fairly high productivity per plant was shown by sample 9978 - 7.815 g and T1311 - 8.6 g. The lowest grain weight per plant was recorded for the Southern Chinese - only 0.73 g, which indicates the extremely low productivity of this variety in the conditions of Northern Kazakhstan. Chinese Domestic produced 4.53g of grain per plant.

The weight of 1000 seeds varied between 20.5 g and 30.5 g. The largest grains were formed by samples T1211 (30.5 g) and the standard Shortandinskaya coarse-grained (30.0 g). The smallest fraction was noted in the sample Southern Chinese - 20.5 g. The remaining varieties occupied an intermediate position in terms of seed size: T1311 - 22.5 g, Chinese Domestic - 22.5 g, T1925 - 23.0 g, 9978 - 26.0 g.

Thus, the analysis of the table showed that the introduced cultivars significantly exceeded the local standard in vegetative plant mass (T1925, 9978, T1311) and height (T1208). Accession T1311 exhibited the most vigorous branching, both first-order and especially second-order, indicating its high productivity potential. Meanwhile, the local standard, Shortandinskaya coarse-grained, was characterized by more moderate growth and branching, which is typical of varieties well adapted to the conditions of northern Kazakhstan and may contribute to better lodging resistance and more uniform ripening.

The local standard Shortandinskaya coarse-grained ranked first in terms of grain number and grain weight per plant. This demonstrates its high adaptability and stable productivity in the soil and climatic conditions of the Akmola region. Among the introduced accessions, T1311 and 9978 stood out, also producing relatively high grain number and weight per plant. At the same time, accessions of Chinese origin (Southern Chinese and Chinese Domestic) demonstrated extremely low productivity rates, which is probably due to their poor adaptation to the sharply continental climate of Northern Kazakhstan and insufficient resistance to local abiotic stresses.

Conclusion. The obtained results confirm the potential of using the local standard as a control, as well as the feasibility of involving individual high-yielding samples (T1311, 9978) in the breeding process to improve the yield structure elements of new buckwheat varieties.

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Art History

THE SOUNDING CHRONICLE OF AN ERA: On the 120th Anniversary of Academician A.K.Zhubanov*

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Abstract. The article is devoted to the multifaceted contribution of Academician Akhmet Zhubanov to the development of Kazakh musical art, scholarship, and education. It highlights the historical significance of his work as a composer, conductor, scholar, and organizer who stood at the origins of Kazakhstan's leading artistic ensembles and cultural institutions, including the Kurmangazy Kazakh National Orchestra of Folk Instruments, the Zhambyl State Philharmonic, the Kurmangazy Kazakh National Conservatory, and other prominent institutions. Particular attention is paid to Zhubanov's role in the formation of national musicology, the development of the scholarly school of art studies, and the establishment of the first dissertation council in the field of art studies in Central Asia. The article presents the international scientific and practical conferences dedicated to the 120th anniversary of Academician Akhmet Zhubanov, held in April 2026 in Aktobe as part of a series of jubilee events, including festivals, concerts, and competitions, as well as in Almaty. It emphasizes the broad participation of leading scholars from Kazakhstan and abroad, together with representatives of cultural and educational institutions. The main directions and contemporary relevance of the conference papers devoted to Zhubanov's creative legacy and theoretical ideas are examined, demonstrating their significance for modern musicological research. The article concludes that Akhmet Zhubanov's legacy continues to retain fundamental importance for the development of national culture, remains a vital spiritual and scholarly foundation of contemporary Kazakh art, and continues to influence the formation of research and educational practices.

Аннотация. Статья посвящена многогранному вкладу академика Ахмета Жубанова в развитие казахского музыкального искусства, науки и образования. Охарактеризовано историческое значение его деятельности как композитора, дирижёра, учёного и организатора, стоявшего у истоков формирования ведущих творческих коллективов и учреждений Казахстана, включая Казахский национальный оркестр народных инструментов имени Курмангазы, Государственную филармонию имени Жамбыла, Казахскую национальную консерваторию имени Курмангазы и другие институции. Особое внимание уделено роли А.Жубанова в становлении отечественного музыкознания, развитии научной школы искусствоведения и создании первого диссертационного совета в Центральной Азии.

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В статье представлены международные научно-практические конференции, приуроченные к 120-летию академика Ахмета Жубанова и проведенные в апреле 2026 года в Актобе – в цикле юбилейных мероприятий (фестивальных, концертных, конкурсных программ) – и в Алматы. Подчеркнуто широкое участие ведущих ученых Казахстана и зарубежных стран, а также представителей творческих и образовательных учреждений. Показаны основные направления и актуальность для современного музыковедения тематики научных докладов, посвящённых творческому наследию и теоретическим идеям А.Жубанова.

Итоговое утверждение – наследие Ахмета Жубанова сохраняет фундаментальное значение для развития национальной культуры, остаётся важной духовной и научной основой современного казахстанского искусства и продолжает влиять на формирование исследовательских и образовательных практик.

Whatever direction of contemporary art in Kazakhstan we consider, the contribution of Akhmet Zhubanov to its formation and development is consistently evident. A vivid confirmation of this is provided by the country's leading cultural institutions and performing ensembles, which were established in the first half of the 20th century: the Kurmangazy Kazakh National Orchestra of Folk Instruments, the Almaty Music College named after Pyotr Tchaikovsky, the Zhambyl State Philharmonic, the Abai Kazakh National Opera and Ballet Theatre, and the Kurmangazy Kazakh National Conservatory. At the origins of their creation stood the outstanding scholar, composer, and public figure, Academician Akhmet Kuanyevich Zhubanov (1906-1968).

He also played an important role in the development of national science. With the establishment of the Academy of Sciences of the Kazakh SSR in 1946, the Section of Art Studies was opened at his initiative, marking the beginning of a new stage in the study of national cultural heritage. Large-scale expeditions were organized to collect and systematize musical folklore, record works of folk talents, preserve valuable cultural “monuments”, transcribe them into musical notation, and introduce them into scholarly circulation.

In addition, at the initiative of Akhmet Zhubanov, the first dissertation council on art studies in Central Asia was established. This made it possible not only for domestic researchers but also for scholars from neighboring republics to defend candidate dissertations.

In 2026, the musical community widely commemorates the 120th anniversary of the birth of Akhmet Zhubanov – an outstanding composer, conductor, People's Artist of Kazakhstan, academician, one of the founders of the Academy of Sciences of the Kazakh SSR and a founder of national art studies and artistic education.

In the city of Aktobe, a large-scale cycle of events titled “Zhubanov Koktemi” (“Zhubanov Spring”), dedicated to his anniversary, has been implemented. Within the framework of the jubilee celebrations, the contribution of this outstanding figure to the development of art, education, and science in Kazakhstan was widely highlighted. Creative ensembles from Astana and Almaty took an active part in the festive events.

If in his time Akhmet Zhubanov made an invaluable contribution to the development of Kazakh art and the strengthening of the foundations of national culture, then today's generation of Aktobe residents continues his spiritual legacy with dignity. Over the course of eight days, numerous cultural events were held in the city, organized at a high professional level and distinguished by their profound content and vivid artistic expression.

Significant support for the implementation of these important initiatives was provided by Akim of Aktobe Region Askhat Shakharov, Head of the Department of Culture, Archives and Documentation of Aktobe Region Altynai Yunusova, and Director of the Aktobe Regional Philharmonic named after Gaziza Zhubanova Dina Niyazova. Thanks to them, cultural and spiritual projects of the region have gained further development and wide public resonance.



Event Poster of Aktobe City



Concert of the Symphony Orchestra of the Republican Specialized Music Boarding School for Gifted Children named after A.Zhubanov, Aktobe, April 28, 2026

Within the framework of the planned series of anniversary events, the International Choral Music Festival “Zhubanov Koktemi – 2026” was held, along with a concert of the Kazakh Chamber Choir of the Aktobe Regional Philharmonic named after Gaziza Zhubanova, a dombra performers’ competition dedicated to the 100th anniversary of Khabidolla Tastanov, an Honored Worker of Arts of the Kazakh SSR, musicologist, educator, and dombra performer, as well as a concert by the faculty of the Kazakh Specialized Music Boarding School for Gifted Children named after A.Zhubanov, among others. One of the most significant events was also the international scientific and practical conference that was organized.



International Scientific and Practical Conference dedicated to the 120th Anniversary of Akhmet Zhubanov (Aktobe, April 28, 2026)

The conference was attended by scholars from the M.O.Auezov Institute of Literature and Art, as well as faculty members of the Kurmangazy Kazakh National Conservatory, the Kazakh National University of Arts named after Kulyash Baiseitova, and the State Conservatory of Uzbekistan.



Shoyista Ganikhanova and
Elmar Buribaev



Participants of the conference

At the opening ceremony of the conference, members of the family of Akhmet Zhubanov also took part, including Gaziza Akhmetovna's son Aday Azerbayzhanovich, Bolat Akhmetovich's daughter Sholpan Bolatovna, and his grandson Elmar Askarovich Buribaev, as well as descendants of Kudaibergen Zhubanov. Their presence gave the forum special significance and emphasized the continuity of generations.

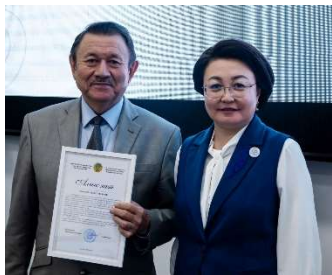
During the conference, the composer's activities as a composer, conductor, educator, and organizer were comprehensively discussed, along with his contribution to the development of musical art, science, and education in Kazakhstan.

Memories of Akhmet Zhubanov were shared by composer and Honored Worker of Kazakhstan Beibit Daldanbay. Welcoming remarks were delivered by A. Zhubanov's great-grandson Elmar Buribaev, as well as by the moderator of the plenary session, PhD Ayzhan Berdibay.

Scholarly presentations were delivered by Doctor of Art Studies, Professor Saule Utegaliyeva ("Scientific Ideas of A.K.Zhubanov in Contemporary Kazakh Ethnomusicology"); Doctor of Art Studies Shoyista Ganikhanova ("The Creativity of Akhmet Zhubanov in the Artistic Context of the Era: Constants and Stylistic Metamorphoses"); Candidate of Art Studies, Professor Aklima Omarova ("A.Zhubanov: "Toward an Unprecedented Flourishing of Musical Art"); Candidate of Art Studies, Associate Professor Ainur Kaztuganova ("Akhmet Zhubanov and the Temple of Science"); PhD Ayzhan Berdibay ("Reflections of the Scholar Akhmet Zhubanov on Kazakh Traditional Music in the 1960s"); Candidate of Art Studies Aigul Baybek ("Academician Akhmet Zhubanov and the Transformation of Kazakh Music Education: Passionate Decolonization and the Paradigm of Ethnosolfeggio"); Gulnara Kuzbakova ("The Opera "Abai" by A.Zhubanov and L.Hamidi in the Context of Contemporary European Stage Direction"); Zulfiya Kasymova ("Transformation of the Semantics of the Wedding Ritual in the Musical Dramaturgy of the Opera "Abai" by A.Zhubanov and L.Hamidi"); and Amanzhol Ismagulov with the paper "The Testament of Academician A.Zhubanov".

In their speeches, participants of the conference discussed key issues related to the study of Akhmet Zhubanov's scholarly, creative, and educational legacy, emphasizing its significance for contemporary musicology and the cultural development of Kazakhstan.

The proceedings of the International Scientific and Practical Conference titled "Founder of Kazakh Professional Music in the 20th Century: On the 120th Anniversary of Akhmet Zhubanov" were also presented [1].



Beibit Daldanbay and Altynai Yunusova



Askhat Shakharov and Dina Niyazbekova



Dina Niyazbekova and Aklima Omarova

The series of events of the "Anniversary Music Week" in the city of Aktobe concluded with a gala concert held on April 29.

On the same day in Almaty, on the initiative of the M.O.Auezov Institute of Literature and Art, and with the participation of the T.Zhurgenov Kazakh National Academy of Arts and the Turkic Culture and Heritage Foundation, the international scientific and practical conference "Akhmet Zhubanov and Contemporary Musicology" was held at a high organizational and academic level, dedicated to the 120th anniversary of the outstanding scholar and cultural figure.

As part of the opening ceremony of the conference, a book exhibition by the Central Scientific Library "Gylym Ordasy", dedicated to Akhmet Zhubanov, was presented to the participants. The exhibition provided visitors with an opportunity to become acquainted with the rich scholarly and creative legacy of the academician.

A special atmosphere at the event was created by the performance of the chamber ensemble of the Kurmangazy Kazakh National Orchestra of Folk Instruments, founded on the direct initiative of Akhmet Zhubanov. The musical program, which organically complemented the content of the conference, provided guests with vivid impressions.

The large-scale international conference brought together leading scholars, musicologists, and faculty representatives from higher education institutions of Kazakhstan, Azerbaijan, Russia, and Kyrgyzstan, as well as members of the Zhubanov family.

Papers were presented by researchers from the Batyraly Sydykov Kyrgyz-Uzbek International University, the Azerbaijan State Pedagogical University, the Institute of History, Language and Literature of the Ufa Federal Research Centre of the Russian Academy of Sciences (awarded the Order of the Badge of Honour), the Institute for Mongolian, Buddhist and Tibetan Studies of the Siberian Branch of the Russian Academy of Sciences, and the Baku Music Academy named after Uzeyir Hajibeyli. The conference also included professors and lecturers from the Kurmangazy Kazakh National Conservatory, the T.Zhurgenov Kazakh National Academy of Arts, the Kulyash Baiseitova Kazakh National University of Arts, M.Utemisov West Kazakhstan University, Kh.Dosmukhamedov Atyrau University, as well as scholars from the M.O.Auezov Institute of Literature and Art.

The broad geographical representation of participants and the high academic level of the presented papers gave the conference international status and contributed to a comprehensive discussion of current issues in musicology and the creative legacy of Akhmet Zhubanov.

At the plenary and sectional sessions of the conference, issues related to the life and creative work of Akhmet Zhubanov were examined, including his activities as a composer, conductor, scholar, educator, public figure, and administrator. Special attention was paid to the legacy of the Zhubanov dynasty in the fields of science and education, as well as to contemporary approaches to the study of literature, language, and the arts.

This academic forum became an important platform for discussing current issues in the study of national musical heritage and its reinterpretation within modern research paradigms. The conference facilitated the exchange of experience among scholars from different countries and helped define prospects for the further development of national musicology and the humanities.

The plenary session was chaired by Kenzhekhan Matyzhanov, General Director of the M.O.Auezov Institute of Literature and Art, Academician.

Welcoming letters were sent to the participants of the conference by Aida Balaeva – Deputy Prime Minister of the Republic of Kazakhstan and Minister of Culture and Information; Sayasat Nurbek – Minister of Science and Higher Education of the Republic of Kazakhstan; Akhylybek Kurishbayev – President of the National Academy of Sciences of the Republic of Kazakhstan; Aktoty Raimkulova – President of the Turkic Culture and Heritage Foundation; Medet Kuanyshev – Director of the Kurmangazy Kazakh National Orchestra of Folk Instruments; Gaukhar Tasbergenova – Rector of the Kurmangazy Kazakh National Conservatory; and Arman Zhudebayev – Rector of the T.Zhurgenov Kazakh National Academy of Arts. These messages once again emphasized the special significance of Akhmet Zhubanov's legacy in the national cultural and scholarly space of Kazakhstan.

The plenary session was attended by Zhenisbek Tolen – Head of the Center for Educational Sciences and Social Development of the National Academy of Sciences of the Republic of Kazakhstan; Aktoty Raimkulova – President of the Turkic Culture and Heritage Foundation; Medet Kuanyshev – Director of the Kurmangazy Kazakh National Orchestra of Folk Instruments; Kabyl Khalykov – Vice-Rector for Research of the T.Zhurgenov Kazakh National Academy of Arts; and Daniyar Bayzhumanov – Director of the Specialized Kazakh Music Boarding School for Gifted Children named after Akhmet Zhubanov.



International Scientific and Practical Conference dedicated to the 120th Anniversary of Akhmet Zhubanov (Almaty, April 29, 2026)

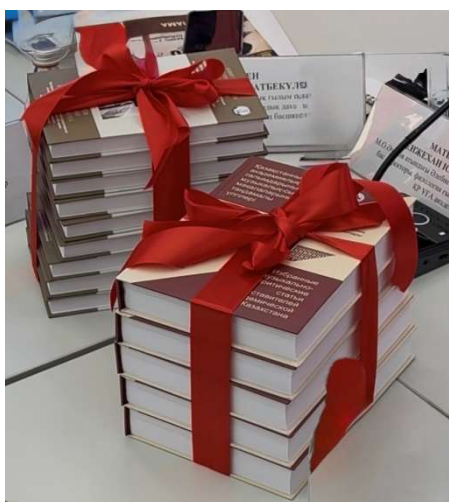
At the plenary presentations, the historical contribution of Akhmet Zhubanov to the formation of Kazakh musical art was comprehensively analyzed, with special emphasis placed on the significance of his scholarly and pedagogical work, as well as his role in establishing national musicology as an independent field of academic study. Considerable attention was given to the reinterpretation of his legacy in the context of contemporary scientific challenges and methodological approaches, which made it possible to present new research interpretations and up-to-date scholarly conclusions.

During the conference, the importance of Akhmet Zhubanov's compositional and academic legacy for contemporary performance practice and the system of music education was widely highlighted. In addition, key issues related to the preservation, systematization, and digitization of national musical heritage were thoroughly discussed, alongside a meaningful exchange of views on the introduction of new research methods and innovative directions in musicology.

Within the framework of the event, the kuys "Zhana Konstitutsiya" ("New Constitution") by Honored Worker of Kazakhstan Shamil Abiltayev was performed, continuing the traditions of Akhmet Zhubanov in the art of kuy. The work was composed in honor of the adoption of the new Constitution of the Republic of Kazakhstan on the initiative of the President of the Republic of Kazakhstan, Kassym-Jomart Kemeluly Tokayev.

An important highlight of the conference was the presentation of two new publications: the book "Selected Samples of Musicological and Critical Articles by Academic Scholars of Kazakhstan" [2], which brings together publications by Akhmet Zhubanov and his followers, and the proceedings of the International Scientific and Practical Conference "Akhmet Zhubanov and Contemporary Music Science" [3]. Both editions were published by "Arna-B", a publishing house known today for producing large-scale and substantial works in the fields of science, education, art, and culture, and recognized for the high quality of its publications.

The compilation and preparation of these academic works were carried out by specialists of the Musicology Department of the M.O.Auezov Institute of Literature and Art, the establishment of which was historically directly connected with the activities of Akhmet Zhubanov.



Ainur Kaztuganova, Zhenisbek Tolen, Medet Kuanyshev, Kenzhehan Matyzhanov, Aktoty Raimkulova, Shamil Abiltayev, Daniyar Baizhumanov

At the sectional sessions of the conference, the interdisciplinary connections of the musical and folkloric heritage of the Turkic peoples were comprehensively examined. Scholars presented substantive papers on current issues in musicology, theatre studies, folkloristics, cultural studies, linguistics, as well as philology and the visual arts.

Special attention was given by participants to the scholarly interpretation of Akhmet Zhubanov's works, including "Musical Alphabet", "Life and Creativity of Kazakh Folk Composers", "Kurmangazy", "Nightingales of the Era", "Strings of the Centuries", "Journey of Song and Kuy" and "The Flourishing of Art". The presentations explored the musical-theoretical aspects of these studies, the poetics and stylistic features of the composer's works, issues of stage interpretation of national art, as well as problems of cultural continuity and interaction among Turkic peoples.

The academic discussions demonstrated a high level of research interest in the legacy of Akhmet Zhubanov and confirmed its enduring significance for the development of contemporary musicology, the humanities, and the cultural space of the Turkic world.



Within the framework of the conference, the ensemble of the T.Zhurgenov Kazakh National Academy of Arts presented a concert program titled “Osken oner” (“Developing Art”), dedicated to the 120th anniversary of the birth of Akhmet Zhubanov. The concert featured well-known cultural figures and performers, including Ramazan Stangazy, Talgat Mukishev, Murat Abugazy, Bolat Zhomartov, Nurzhan Zhampyisov, Sholpan Darzhan, Talgat Abugazy, Korlan Kartenbayeva, Armat Islamgaliev, Syrymbet Nurmoldin, Zhanbolat Zhumagazin, Kalamkas Kadyrbayeva, Togzhan Duisenbekkyzy, Zhanat Mukanov, Gali Kakimbay and Satys Eskendir.

A special place in the program was given to the works of Akhmet Zhubanov performed by the dombra ensemble and the academy’s student choir under the direction of Syrymbet Sailybayev. The performances allowed the audience to once again experience the rich musical heritage of the outstanding composer and scholar.

The jubilee concert was hosted by Murat Abugazy, Associate Professor of the T.Zhurgenov Kazakh National Academy of Arts, kui performer, and holder of the title “Cultural Figure of the Republic of Kazakhstan”. In his commentary, he vividly highlighted the multifaceted personality of Akhmet Zhubanov through examples from his life and creative path, emphasizing the invaluable contribution of the academician to the development of national culture and spirituality.



Concert dedicated to the 120th Anniversary of Akhmet Zhubanov (Almaty, April 29, 2026)

In conclusion, it should be noted that the large-scale complex of events dedicated to the 120th anniversary of the birth of Academician Akhmet Zhubanov comprehensively demonstrated his invaluable contribution to the development of Kazakh musical art and national scholarship. The jubilee events, international academic conferences, and cultural and creative projects held in Aktobe and Almaty convincingly confirmed that Zhubanov's legacy represents a lasting spiritual value whose significance is not limited by time.

The composer's activities as a composer, conductor, educator, and organizer were reinterpreted as a solid foundation of contemporary Kazakh musicology and gained new meaning in light of current scholarly approaches. At the same time, it was clearly demonstrated that the cultural institutions and academic schools established on his initiative continue to remain viable and play an important role in the country's contemporary cultural space.

Akhmet Zhubanov's legacy is not only an outstanding achievement of the past but also one of the most important spiritual reference points of modern society. His life and creative path remain a vivid example of devoted service to national culture, education, and science, while his ideas and works continue to shape the prospects for the development of national art and the humanities.

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HOW “OYU FEST” CHANGED THE MUSICAL CULTURE OF KAZAKHSTAN: HISTORY, ARTISTS, AND THE EVOLUTION OF THE FORMAT (2022-2026)¹

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Abstract. This article examines how the “OYU Fest” festival transformed Kazakhstan’s music industry and culture between 2022 and 2026. It traces the project’s entire journey: from intimate live performances on YouTube (OYU Live) to a massive two-day anniversary festival in Almaty. The main focus of the article is on how the organisers select artists. By bringing together indie rock, rap, legends of Soviet pop (the Dos-Mukasan vocal-instrumental ensemble, Roza Rymbaeva) and stars of the mainstream toi scene (Kairat Nurtas) on one stage, “OYU Fest” blurs the boundaries between generations and breaks down old stereotypes.

Contemporary Kazakh culture is currently going through a very inspiring period: it is gently moving away from old, familiar patterns and rediscovering its distinctiveness and independence. For a long time, there was a divide in the music industry: in the cities, people mainly listened to Russian pop, whilst Kazakh songs were considered “out of fashion” and associated only with weddings and rural areas.

Everything changed in the mid-2010s with the emergence of the band “Ninety One”, who pioneered a new genre – Q-pop. The band combined vibrant global trends with the Kazakh language, showing young people just how beautiful, stylish and contemporary their native tongue can sound.

At the same time, an independent movement known as “Qazaq Indie” emerged. Young musicians began blending contemporary rock and electronic music with folk motifs, whilst thoughtfully exploring the country’s history and important social issues in their songs.

The OYU project has become the real link between all this new music. It originally began as a cosy niche YouTube show called OYU Live¹, whose creators sought to capture the live sound of Central Asian musicians. They showcased pop artists, indie rockers and folk musicians playing the dombra, all presented in an equally stylish, modern and aesthetically pleasing visual format.

Live performances have become so popular with audiences that their huge success online provided the impetus for the creation of the large-scale annual “OYU Fest”. Today, thousands of young people gather at concert venues to sing their favourite songs in Kazakh together. This new musical wave has harmoniously blended the traditions of the past with the rhythm of modern life, making Kazakhstani culture truly self-sufficient, vibrant and relatable to the new generation.

¹ This work was carried out within the framework of the project of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan BR31715839 “Fundamental Research in Literary and Art Studies: Academic Continuity and New Paradigms”.

Whilst the OYU Live YouTube show itself launched in early 2021, the large-scale open-air festival “OYU Fest” first made a big splash in the summer of 2022. The very first “OYU Fest” took place in July 2022, responding to the huge interest from viewers in the online project and becoming a unique space which Kamilla, one of the organisers, described as: “It’s as if we’ve created a summer Nauryz” [1].



The defining feature of “OYU Fest” is the way the organisers select their artists. They deliberately avoid rigid musical boundaries and the division of music into “highbrow” and “popular”. In the past, musical tastes in Kazakhstan often divided people into different groups depending on where they lived or what language they spoke. The festival breaks down these invisible barriers, bringing everyone together in one place. Completely different genres coexist harmoniously on the festival stage. Audiences can start by listening to traditional music (kuy on the dombra), then dance to modern Q-pop, and afterwards immerse themselves in the atmosphere of indie rock or rap. Moving from a complex online archive to a major open-air celebration, the festival demonstrates that folk classics, street hip-hop and pop music are all equally valuable to contemporary culture. This approach brings together a completely diverse audience – from sophisticated urban music lovers to fans of mainstream pop – helping them to understand one another better and feel part of one big, friendly country.

Below is a timeline of the festival’s development from 2022 to 2026. The table clearly shows how the project has grown: from its first concerts in Almaty to large-scale shows in the two capitals, featuring legends of yesteryear and today’s biggest stars.

30 July 2022	29 July 2023	1 June 2024 (Almaty)	24 May 2025 (Almaty)	4 July 2026 Day 1 in Almaty
Menindenimsaw	Kunzharyq	Ayau	ALPHA	Sadraddin
Akha	Asiya	Kunzharyq	Dudeontheguitar	ALPHA
M'Dee	Ayau	Marhaba Säbi	Daiynball	Kunzharyq
Dose (Aydos Dzhumalinov)	Dudeontheguitar	Aikyn	Orynkhan	"The Exclusive Club' (M'Dee, Ayau and Rusha)
Ali	Dequine	Shiza	Yenlik	Yenlik
Yenlik	ARShAT & Kuanyshbek Nurgazy	Dequine	6ELLUCCI	ARO
ORDA	Second Ka	Irina Kairatovna	jeltoksan	Almás
ORYNKHAN	Moldanazar	Nurlan & Murat	Shiza	on alty
ARO	Kazybek Kuraiysh	27 July 2024 (Astana)	Alem	The festival's headliner on the first day Berkut & Aisha
ZOLOTO	ARO	TYNYQ	Kezeñ	5 July 2026 Day 2 in Almaty
MOLDANAZAR	Shiza	Asiya	The festival's headliner, "Dos Mukasan"	Dequine
Ninety One	Ninety one	Sadraddin	28 June 2025 (Astana)	Orynkhan
JAMANT	Yerbolat Kudaibergen	ARO	Moldanazar	Qazaq Indie (dudeontheguitar, SAMRATTAMA and Zere)
The festival's headliner, Kairat Nurtas		AIKYN	Dos Mukasan	abdr.
		Dequine	ALPHA	Rin'Go
		Shiza	Irina Kairatovna	ken dala
		Nurlan & Murat	Ayau	dosm.
		The festival's headliner, V \$ X V PRINCE	Kunzharyq	The headliner on the second day of the festival is Roza Rymbaeva
			Asiya	
			Shashoo	
			6ELLUCCI	
			Alem	
			Headliner of the festival in Astana Kairat Nurtas	

As well as its brilliant musicians, "OYU Fest" has its own charismatic presenters who create that warm, friendly and heartfelt atmosphere on stage. The festival's presenters aren't just people who announce the acts. They connect with the stadium on the same wavelength, crack jokes, support the artists and help thousands of completely different audience members feel like one big

family. Year after year, the project’s hosts are well-known local influencers, entertainers and bloggers who genuinely love the new Kazakh culture and promote it to the masses.

Year	Presenters
2022	Abai Kabdrashitov – (@abailuck)
2023	Nagimush Nastievich (@nagimuwaa) and Jomart Aralbaiuly (@aralbaiuly)
2024	Almagul Kazikhan-Sagyndyk (@almasagindik) and Almaz Merzhakypov (@mvsstoi)
2025	Nagimush Nastievich (@nagimuwaa) and Almaz Merzhakypov (@mvsstoi)

If you want to experience the full energy of live performances, see the artists’ spectacular shows for yourself, or rewatch your favourite moments, you can watch the full concert via the link on the project’s official YouTube channel².

The “OYU Fest” kicks off long before the headliners take to the stage, and it’s the talented local DJs who set that powerful opening vibe. Whilst guests gather, chat and wander around the site, the venue transforms into a huge open-air dance floor. As the organisers themselves say: “Before the artists perform, we all get the party started with DJ sets’2”³. The DJs don’t just play popular tracks; they create unique mixes where modern electronic beats, house and techno are stylishly interwoven with Kazakh folk motifs and retro hits. This gets the crowd in the right mood and energises them for the whole day.

Year	DJ
2023	Sarah(Sarah Baid), Arsén Rysdaulét (DJ Arsen Superfly)
2024 (Almaty)	Nazira (@nazira_in_zvuk), AKEE (@dj_akee_)
2024 (Astana)	Mark Redlights (@mark.redlights), DJ Rahalook (@rahalook)
2025 (Almaty)	Edigee (@edigeeeeeeee), Rusha
2025(Astana)	DJ Rahalook (@rahalook), Anele (@ane11ee)

2026 marks a special milestone for “OYU Fest” – this year the project celebrates its 5th anniversary. To mark this major anniversary, the organisers are preparing a show on an unprecedented scale. Unlike previous years, the anniversary “OYU Fest” 2026 will take place exclusively in Almaty – the cultural capital and home of the project. The organisers have decided to concentrate all their resources, efforts and exclusive programme at a single spectacular venue. The main highlight this year is that, for the first time in its history, the festival will run for a full two days. This means that attendees will have twice as much time to soak up the atmosphere of contemporary Kazakh culture and let their hair down. The two-day format will make this celebration of domestic music even more powerful. Guests can look forward to even more live music, non-stop dancing to DJ sets, conceptual shows from artists and an unforgettable festive vibe.

The five-year journey of “OYU Fest” (2022-2026) shows how a single creative project can completely reshape the music industry and cultural landscape of Kazakhstan. What began as an

² 2022 – https://youtu.be/sbdHeotUKwc?si=sDGI_IJb-UtOrNTK

2023 – <https://youtu.be/nK5pbuJYubY?si=1nSwSDUIL27Atgxe>

2024 – https://youtu.be/fi9yp9-ZG5w?si=St_Hx2_5dBfimtld

2025 – <https://youtu.be/EKho9RNnm6A?si=5wz9pluyMDaDtp8y>

³ It is worth noting that the quote, the lists of artists and the details about the festival have been taken directly from OYU’s official Instagram account and other public sources

https://www.instagram.com/oyu.fest?utm_source=ig_web_button_share_sheet&igsh=ZDNlZDc0MzlxNw=



intimate YouTube show has grown into a massive annual celebration that does much more than just entertain – it brings people together and changes how a country views its own culture.

By breaking down the invisible walls between different genres and audiences, the festival has created a unique space where indie rock, underground rap, mainstream pop, and legendary Soviet-era classics coexist harmoniously. This blend of styles has helped bridge the gap between generations and completely shattered the old stereotype that Kazakh-language music couldn't be trendy or modern. Today, singing and dancing to songs in the native language has become the ultimate symbol of youth identity and pride.

This success comes at a time when Kazakhstan is experiencing a real boom in outdoor music festivals, with new events popping up across the country every year. In this rapidly growing movement, “OYU Fest” stands out as a true pioneer. With its unique atmosphere, incredible scale, and massive influence on youth style and lifestyle, “OYU Fest” is fast becoming Kazakhstan’s own Coachella. It has evolved past a simple concert lineup into a major cultural landmark and a trendsetter for the entire region.

Ultimately, by turning a music festival into a modern “summer Nauryz,” the organizers have proven that traditional roots and modern pop culture don’t just live side by side – they make each other stronger. “OYU Fest” has successfully captured the spirit of a new, independent, and self-sufficient Kazakhstan culture, making it vibrant, exciting, and deeply relatable for the new generation.

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