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Economic Sciences

Современные подходы к реализации проектного менеджмента

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Проектное управление представляет собой основополагающий элемент системы менеджмента компании [1]. В условиях интенсификации деятельности хозяйствующих субъектов и высокой конкуренции эффективная система проектного управления выступает как ключевой фактор успеха, предоставляющий конкурентное преимущество. Эффективный менеджмент организации обеспечивается изучением и грамотным применением моделей проектного управления, однако в стремительно меняющихся условиях рынка необходимым представляется переход к новым моделям проектного управления, дающим возможность выстраивать высокоэффективную систему менеджмента проектов [2]. Наиболее перспективными являются гибкие методы проектного менеджмента, основанные на хорошо выстроенных механизмах и схемах коммуникаций и информационного обмена стейкхолдеров. В связи с этим актуальным является исследование особенностей современных методик проектного менеджмента.

Целью работы является изучение современных подходов к реализации проектного менеджмента. Для её достижения были использованы методы анализа и синтеза научных публикаций и литературных источников по рассматриваемой теме.

Под проектным менеджментом понимается методология организации, руководства, планирования и координации трудовых, материально-технических и финансовых ресурсов на протяжении всего проектного цикла, ориентированная на эффективное достижение его конечных целей посредством применения современных техник, методов и технологий управления [3]. Методы проектного менеджмента используются для:

- определения целей проекта и его обоснования;
- выявления структуры проекта;
- определения требуемых объёмов и источников финансирования;
- подбора исполнителей;
- подготовки и заключения контрактов;
- определения сроков и составления графика реализации проекта;
- расчёта необходимых ресурсов, сметы и бюджета проекта;
- планирования и учёта рисков;
- обеспечения контроля за ходом реализации проекта.

Следует различать понятия «проектный менеджмент» и «управление проектами», дифференцирующим признаком которых является объект управления [4]. В управлении проектами объектами управления выступают программы, проекты и портфели проектов, тогда как в проектном менеджменте – организация как группа лиц, которая сформирована на долгосрочной основе для осуществления определённой деятельности и достижения единой цели. Целью управления проектами является успешная реализация проекта, заключающаяся в достижении результата в рамках установленного технического задания, а проектного менеджмента – получение организацией прибыли, достижение устойчивого экономического положения и прочее.

Можно выделить следующие основные принципы проектного менеджмента [5]:

- целенаправленность – целевая ориентации проекта;
- системность – рассмотрение проекта с системных позиций, что позволяет целостно анализировать процесс управления проектами, одновременно разбивая его на подсистемы;
- комплексность – рассмотрение явлений в их взаимосвязи и взаимозависимости;
- обеспеченность – укомплектованность всех предусмотренных проектом мероприятий необходимыми для их реализации видами ресурсов;
- приоритетность – предоставление преимущества первоочередным задачам при разработке и реализации проекта;
- экономическая безопасность планируемых мероприятий.

Проектный менеджмент даёт возможность управлять организацией в режиме развития, при котором наращивается её производственный потенциал и осваиваются инновации, что приводит к увеличению показателей деятельности [6]. Результатом проектной деятельности выступают любые процессы, продукты, услуги, программное обеспечение, стандарты и компетенции (личностные, коммуникативные и информационно-коммуникационные). Посредством проектного менеджмента обеспечивается возможность адекватной реакции руководства компании на внешние изменения посредством продуманных внутренних трансформаций.

Основным преимуществом проектного менеджмента является предоставление участникам проекта возможности взглянуть на проблему как со своей профессиональной точки зрения, так и с позиции экспертов смежных областей за счёт получения обратной связи [7]. Только в случае, когда все члены команды беспристрастно и систематически оценивают проблему и совместно применяют различные методы для принятия окончательного управленческого решения, становится возможным достижение должного уровня качества реализации и объективности задачи.

Несмотря на значительную теоретическую базу проектного менеджмента, на практике проекты часто терпят неудачи, причинами которых являются [8]:

- изменение внутренних приоритетов организации;
- неточность требований;
- изменение целей проекта во время его реализации;
- неопределённость рисков или целей проекта;
- плохо налаженная коммуникация;
- неадекватная спонсорская поддержка либо смета расходов;
- неточность оценки времени, необходимого для выполнения отдельных задач;
- ресурсозависимость или неадекватное прогнозирование ресурсов;
- некачественное управление изменениями;
- неопытность менеджера проекта.

С целью решения указанных проблем компании постепенно переходят от классического подхода к управлению проектами, основанного на предположении о низких рисках, неизменности требований и жёстких сроках, к гибким и более адаптивным методологиям управления [9]. Адаптивным системам проектного менеджмента присущи следующие отличительные особенности:

1. Ориентированность на конкретный результат. Все выполняемые во время внедрения идеи действия взаимосвязаны и ориентированы на достижение заранее определённой цели. При реализации проекта первостепенным аспектом становится завершённость всех процессов.

2. Ограниченность в ресурсах. Для эффективного воплощения проекта необходимо грамотное распределение имеющихся человеческих, финансовых и

временных ресурсов, осуществляемое посредством установления точного либо приблизительного срока завершения работ, составления сметы и графика реализации.

3. Уникальность. Гибкий подход к проектному менеджменту наиболее эффективен в случае создания нового товара или внедрения новой услуги.

Методики гибкого проектного менеджмента основаны на полной открытости и постоянном обмене информацией между всеми стейкхолдерами и внутри проектной команды, что позволяет объединить все локальные аспекты проекта в единую систему, посредством которой возможно повышение эффективности деятельности компании в условиях высокой неопределённости внешней среды. В рамках современных подходов важна не только и не столько онлайн-коммуникация, сколько личный обмен информацией, однако в зависимости от потребностей проекта и имеющихся в распоряжении ресурсов подходы к работе, а также сложность и уровень используемых технологий могут различаться. Целью формирования сбалансированного пакета коммуникационных инструментов является предоставление всем членам команды возможности эффективно обмениваться данными, корректировать и синхронизировать собственные действия, оперативно учитывая изменения в проектной среде. Помимо этого, коммуникационный инструментарий должен позволять менеджерам проекта не только осуществлять постоянный мониторинг за ходом выполнения проекта, но и своевременно влиять на его результаты.

Основной методикой гибкого проектного менеджмента является Agile, ориентированная на гибкое итеративное управление проектами компании [10]. Согласно данному подходу, весь проект разбивается не на стандартные последовательные этапы, а на совокупность взаимосвязанных подпроектов. Стратегическое планирование и инициация реализуются для проекта в целом, тогда как выделение предстоящих фаз управления и детализация работ осуществляются отдельно для всех подпроектов. Подобная организация проектной деятельности даёт компании возможность оперативнее получить запланированный результат, а в случае необходимости внесения изменений в отдельный подпроект – сделать это без существенных дополнительных затрат и корректировки остальных частей проекта.

Методология Agile базируется на следующих основных принципах [11]:

- возможность изменения требований на любом этапе разработки;
- удовлетворение клиентских потребностей благодаря ранней и бесперебойной поставки ценности;
- частое обсуждение промежуточных результатов;
- непрерывное общение заказчика с командой разработчиков в течение всего проекта;
- мотивированность исполнителей проекта, обеспеченных не только

необходимыми материальными условиями для работы, но и доверием и поддержкой;

- открытость, преимущественно личная передача всей информации;
- использование работоспособности продукта или процесса в качестве показателя прогресса;
- постоянное внимание к удобству и повышению уровня мастерства;
- возможность разработчиков, спонсоров и пользователей поддерживать постоянный рабочий темп;
- оптимизация рабочих процессов;
- способность команды к самоорганизации;
- перманентная адаптация к изменяющимся обстоятельствам.

Согласно идеологии Agile, взаимодействие и люди ставятся выше инструментов и

процессов, работающий продукт – выше исчерпывающей документации, сотрудничество с заказчиками – выше подготовки контракта, а готовность к переменам – выше, чем следование изначальному плану.

Наиболее популярным и структурированным из семейства технологий Agile является фреймворк Scrum, удачно сочетающий элементы классического и гибкого подходов к организации управления проектами. Сущность Scrum сводится к набору правил самоорганизации мультидисциплинарной проектной команды, включающей владельца продукта, команду разработчиков и scrum-мастера [12]. Такая командная модель предполагает обеспечение творчества и гибкости исполнителей и сведение к минимуму внешних зависимостей. Фреймворк Scrum подразумевает разделение всего проекта на спринты – равные по длительности части, в течение которых необходимо достигнуть заранее определённых результатов. Продолжительность спринта обычно составляет от одной до четырёх недель. Перед началом спринта на командном совещании составляется список задач для бэклога, оценивается время, требуемое для выполнения каждой задачи, и обсуждается взаимодействие между членами команды. По результатам завершения спринта команде необходимо предоставить заказчику пригодный к использованию продукт. Такой подход обеспечивает максимальную гибкость разработки и позволяет корректировать задачи на любом этапе разработки.

Таким образом, проектный менеджмент выступает одним из ключевых инструментов эффективного управления организацией. В условиях динамичных изменений экзо- и эндогенной среды экономических систем разного уровня требуется переход от управления на базе жёстких структур к гибкому управлению, в частности – адаптивному проектному управлению. Инструментарий проектного менеджмента в управлении компаниями позволяет не только согласовывать интересы стейкхолдеров в вопросах развития, но и оценивать эффективность применения имеющихся и заёмных ресурсов и перспективность вариантов возможных решений существующих проблем.

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Идентификация и управление рисками в проектах: современный подход

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Управление рисками в области строительства представляет собой важнейший аспект для успешной реализации проектов. В этой статье обсуждаются ключевые риски, оказывающие влияние на строительные процессы, а также современные подходы к их выявлению и снижению. Оценивается воздействие колебаний цен на строительные материалы, задержек в поставках, ошибок в проектной документации, административных препон и погодных условий. В работе также представлены как количественные, так и качественные методики оценки рисков, такие как SWOT-анализ, метод Дельфи и метод ожидаемой денежной стоимости (EMV). В заключение статьи сформулированы стратегические рекомендации для повышения устойчивости строительных проектов и уменьшения вероятности возникновения серьезных угроз.

Ключевые слова: управление рисками, строительные проекты, анализ рисков, риски, цифровизация строительства, прогнозирование рисков, BIM-моделирование, влияние погодных условий, стратегия минимизации рисков.

Управление строительными проектами невозможно без учета рисков, поскольку данная отрасль характеризуется значительной степенью неопределенности. Факторы, такие как колебания цен на строительные материалы, сбои в поставках, изменения в нормативно-правовой базе, проектные ошибки и неблагоприятные погодные условия, могут существенно повысить расходы и задержать выполнение работ. Необходимость планирования и минимизации этих рисков становится ключевым аспектом эффективного управления проектом. Применение современных подходов к оценке и управлению рисками помогает строителям предвидеть потенциальные проблемы и принимать меры для их снижения. Таким образом, грамотное управление рисками не только способствует более эффективному использованию ресурсов, но и способствует соблюдению сроков выполнения проекта, гарантируя его успешное завершение.

По данным McKinsey Global Institute (2023), более 70% строительных проектов сталкиваются с перерасходом бюджета, а 60% завершаются с задержками. Это указывает на необходимость системного подхода к управлению рисками, основанного на аналитических методах прогнозирования и минимизации негативных факторов.

Цель данной статьи — проанализировать ключевые риски строительных проектов и предложить практические решения, позволяющие минимизировать их последствия.

Классификация и анализ ключевых рисков

В процессе реализации строительных проектов можно выделить несколько наиболее значимых рисков, которые оказывают наибольшее влияние на сроки и бюджет строительства.

1. Рост стоимости строительных материалов

Одним из наиболее распространенных рисков является увеличение цен на строительные материалы. За последние пять лет стоимость ключевых ресурсов, таких как цемент, арматура и металлоконструкции, увеличилась на 20–40%.

Колебания цен на сырье могут привести к перерасходу бюджета на 10–15%, что критично для крупных строительных объектов.

Меры минимизации:

- Заключение долгосрочных контрактов с фиксированной ценой;
- Диверсификация поставщиков для снижения зависимости от одного рынка;
- Использование биржевых инструментов и стратегий хеджирования ценовых рисков.

2. Ошибки в проектной документации

Недостатки проектной документации могут привести к переделке строительных конструкций, увеличению сроков и возникновению дополнительных расходов. По оценкам экспертов, исправление ошибок на этапе строительства увеличивает затраты на 5–8% от общей стоимости проекта.

Меры минимизации:

- Проведение многоуровневой проверки проектной документации перед началом строительства;
- Использование BIM (Building Information Modeling) для выявления возможных коллизий на ранних стадиях;
- Введение строгого контроля качества проектирования с участием независимых экспертов.

3. Задержки поставок и ненадежность подрядчиков

Сбои в поставках строительных материалов и низкая надежность подрядчиков приводят к срыву графика работ. Анализ строительных проектов показывает, что около 50% задержек связано именно с поставщиками и подрядными организациями.

Меры минимизации:

- Контрактная система с четкими условиями поставок и штрафными санкциями;
- Создание резервного запаса критически важных материалов;
- Внедрение цифровых систем мониторинга работы подрядчиков.

4. Регуляторные и бюрократические риски

Изменение законодательства в сфере строительства может потребовать пересмотра проектной документации и корректировки проектных решений. За последние пять лет в строительной отрасли введено более 30 новых нормативных актов, что усложняет процесс согласования.

Меры минимизации:

- Проведение юридического аудита проекта до начала работ;
- Взаимодействие с государственными органами на стадии проектирования;
- Использование электронных систем документооборота для ускорения согласований.

5. Неблагоприятные погодные условия

Климатические условия оказывают значительное влияние на темпы строительства. В зимний период в ряде регионов строительные работы могут быть приостановлены на 30–40% рабочего времени.

Меры минимизации:

- Планирование графика строительства с учетом сезонности;
- Применение современных технологий, позволяющих вести работы в сложных климатических условиях (например, прогрев бетона);
- Разработка альтернативных сценариев выполнения работ.

Методы оценки рисков

Для эффективного управления рисками необходимо применять аналитические методы оценки их вероятности и последствий. В данной работе рассмотрены три ключевых метода: SWOT-анализ, метод Дельфи и метод ожидаемой денежной стоимости (EMV).

SWOT-анализ

SWOT-анализ позволяет выявить сильные и слабые стороны строительного проекта, а также оценить потенциальные угрозы и возможности.

Фактор	Примеры
Сильные стороны	Применение цифровых технологий, контроль качества
Слабые стороны	Высокая зависимость от подрядчиков, риски поставок
Возможности	Государственные субсидии, новые технологии
Угрозы	Рост цен, задержки поставок, изменения в законодательстве

Метод Дельфи

Метод Дельфи используется для оценки рисков путем получения экспертных мнений. Он применяется в ситуациях, когда недостаточно статистических данных или требуется субъективная оценка вероятности и последствий рисков. Данный метод основывается на анонимных опросах группы экспертов, проводимых в несколько этапов, чтобы достичь максимально объективных результатов. Например, вероятность наступления некоторых рисков отличается. Рост стоимости материалов примерно 70%, Ошибки в проекте 50%, Задержка поставок 40%, Погодные условия 60%

Метод Дельфи используется для оценки рисков путем экспертного прогнозирования. В рамках данного исследования данный метод был адаптирован на основе анализа отраслевых отчетов, публикаций консалтинговых компаний и данных международных организаций. Вероятностные оценки рисков основаны на динамике изменений стоимости строительных материалов за последние пять лет, статистике задержек поставок и анализе влияния климатических факторов на строительные процессы. Подход включает комплексную обработку экспертных мнений и статистических данных, что позволяет обоснованно определить вероятность возникновения ключевых рисков и их влияние на реализацию строительных проектов.

Метод ожидаемой денежной стоимости (EMV)

EMV позволяет рассчитать потенциальные финансовые потери при возникновении рисков.

Метод ожидаемой денежной стоимости применяется для количественной оценки рисков, позволяя прогнозировать потенциальные финансовые потери. Расчет основан на данных о вероятности возникновения рисков и оценке их финансовых последствий, полученных на основе анализа бюджетов реализованных строительных проектов. В расчетах учитывались прогнозируемые изменения цен на строительные материалы, возможные затраты на устранение ошибок проектирования, задержки поставок и влияние климатических факторов. Полученные значения позволяют определить финансовую уязвимость строительного проекта и разработать стратегии минимизации рисков.

Риск	Вероятность (P)	Потери (L), млн тг	EMV = P × L (млн тг)
Рост стоимости материалов	0.75	180	135
Ошибки в проекте	0.5	75	37.5
Задержка поставок	0.4	30	12
Погодные условия	0.6	20	12

Стратегии управления рисками

Для эффективного контроля рисков необходимо внедрять комплексные меры управления:

1. Прогнозирование и мониторинг – анализ цен, поставок и нормативных изменений.
2. Цифровизация процессов – применение BIM, автоматизированных систем управления проектами.
3. Финансовая защита – создание резервных фондов и страхование.
4. Контроль подрядчиков – строгие контракты, рейтинговые системы и независимый аудит.

Строительная отрасль характеризуется высокой степенью неопределенности, что делает управление рисками обязательным элементом проектного менеджмента. Анализ ключевых угроз, применение современных методов оценки и стратегическое планирование позволяют снизить потери и повысить устойчивость проектов.

Компании, внедряющие системный подход к управлению рисками, способны реализовывать проекты в срок, в рамках бюджета и с высоким уровнем качества. Это подтверждает, что риск-менеджмент является не только инструментом минимизации потерь, но и важным фактором конкурентоспособности в строительной сфере.

Предложенные методы оценки рисков позволяют повысить предсказуемость строительных проектов, снизить неопределенность и минимизировать потенциальные убытки. Практическая реализация таких инструментов, как цифровое проектирование, оптимизация логистических процессов и применение контрактных механизмов управления рисками, способствует повышению устойчивости строительной отрасли. Внедрение системного подхода к управлению рисками позволяет строительным компаниям достигать поставленных целей в рамках запланированных сроков и бюджета, обеспечивая стабильность и эффективность реализации проектов.

НОВЫЕ ТЕХНОЛОГИИ В СТРОИТЕЛЬСТВЕ И АРХИТЕКТУРЕ КАЗАХСТАНА

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В последнее десятилетие на территории Республики Казахстан была проведена большая аналитическая и законодательная работа по совершенствованию нормативной базы в целях обеспечения более эффективной работы субъектов инновационного развития.

Однако, в целом, роль инновационных технологий в развитии строительства и архитектуры остается незначительной. На современном этапе социально-экономического развития предприятия стремятся внедрять новые технологии, повышать качество продукции. Это увеличивает и конкурентоспособность, реализуются новые архитектурно - планировочные решения, конструкции фундаментов и облицовка фасадов, технология отделочных работ, строительство дорог и другие инновационные проекты.

Закупка зарубежных технологий и создание в стране современных производств различных строительных материалов, а также насыщение рынка материалами зарубежного производства, хотя и позволили уменьшить дефицит в качественной и эффективной продукции строительного назначения, однако, не исключили потребность в новых строительных материалах и особенно - дешевых материалах.

Сегодня на фоне сохраняющейся тенденции постоянного удорожания стоимости жилья удешевление строительных материалов и самого строительства чрезвычайно актуально.

Кроме того, широкая практика применения импортных материалов в городской застройке, например, материалов фасадной облицовки, выявила негативную реакцию на облицовочные плиты с гладкой лицевой поверхностью, при этом наметилась потребность в облицовочных плитах с рельефной поверхностью, морщинистых, с рельефом колотого камня и др.

Современная архитектура отказывается от типового массового строительства. Решается эта задача, в том числе и применением новых отделочных материалов, в ряду которых своя роль отводится искусственному камню.

В настоящее время достаточно широкое распространение получили камни на основе цемента. Разработчики предлагают для облицовки фасадов зданий использовать различные композиционные материалы и изделия, в том числе на основе гипса. Гипсовая масса легко готовится, великолепно льется, способна до мельчайших подробностей воспроизвести рельеф подложки, затвердевает без усадки и трещин. Гипс доступен, дешев, быстро затвердевает, изделия из него имеют достаточно высокую прочность.

К сожалению, высокое водопоглощение и низкая водостойкость этого материала ограничивает его использование для наружных работ. Этот недостаток гипса устраняется в композиционных материалах, где коренным образом модифицируется структура гипсового камня, значительно улучшаются его свойства, особенно водостойкость, и, что особенно важно, сохраняются преимущества гипса.

Материалы, используемые в строительстве, делятся на различные подгруппы. Это деление не зависит от того, каким образом они производились, поскольку принимаются во внимание иные факторы. Отдельную группу занимают композиционные строительные материалы, под которыми понимают материалы со сцементированным в общий монолит различных связующих компонентов и заполнителя. Чаще всего они состоят из армирующего компонента и матрицы. Матрица — это непрерывный в объеме компонент, он же является и связующим. Те компоненты, которые распределяются в матрице в форме волокон или пластин, принято называть дисперсной арматурой. Матрицы также имеют свои подвиды, и по признаку вещественной природы их делят на: неорганические, металлические, полимерные, комбинированные (то есть, полиматричные). Классификация армирующих компонентов базируется на геометрических признаках и их порядка расположения в матрице.

По второму признаку их делят на: дисперсно-армированные, то есть анизотропные; дисперсно-упрочненные, то есть изотропные. Композиционные строительные материалы могут обладать низкой плотностью с высокой прочностью. Но это не означает, что они теряют из-за этого какие-либо свои преимущества. При этом им свойственна долговечность в сочетании с высокой прочностью и эксплуатационной стойкостью. Благодаря этому они могут активно противостоять различным внешним воздействиям, сохраняя тем самым возведенные с их использованием здания.

Также современные композиционные строительные материалы позволяют максимально снизить нагрузку на фундаменты и сделать процесс строительства намного более простым. Материалоемкость конструкций в итоге также снижается в 3–7 раз, что также благоприятно влияет на процесс строительства.

Свое применение они нашли в основном в следующих областях: качестве конструкционных или конструкционно теплоизоляционных материалов с улучшенными строительно-эксплуатационными свойствами; в качестве замены металла или иных дефицитных традиционных материалов.

Прозрачный бетон - новейшая технология появилась всего лишь несколько лет назад. Обычные фасады уже строятся с её использованием. Идея прозрачного бетона достаточно проста. В бетонный блок или в бетонную панель вживляется небольшой процент светопроводящего волокна. Волокна распределяются по поверхности бетона достаточно равномерно. Достаточно подсветить обратную сторону бетонного элемента, чтобы на его лицевой стороне также появился свет. Всего лишь несколько процентов волокна дают не только увидеть наличие света, но и передать цвета и даже контуры фигур, находящихся внутри помещения. Технология влечёт за собой важное следствие - в полумраке бетонная конструкция может светиться.

Эстетическая сторона использования прозрачного бетона в фасадном строительстве ещё требует своего осмысления и проверки на практике. Несомненно, что лёгкость и воздушность внешнего вида светящегося бетона напрямую противопоставляется тяжёлому виду бетона, особенно в сумерках и ночью.

Традиционное световое оформление таких массивных форм зачастую не только не делает их легче, но даже подчёркивает их тяжесть и доминирование, что хорошо для тоталитарного стиля, но совершенно неприемлемо в современной городской среде. А вот прозрачный, светящийся изнутри бетон, выглядит совершенно иначе.

Поэтому, возможно, бетонные фасадные конструкции приобретут новую жизнь, поскольку технически в использовании таких блоков и панелей не видно существенных проблем. Особенно перспективным выглядит использование прозрачного бетона для устройства фасадов небольших городских строений и павильонов, в частности, торгового

назначения. Они должны быть привлекательными в любое время суток, а безопасная установка внешнего освещения не всегда проста и экономична.

На самом деле история создания некоторых композиционных материалов началась еще давно, но на немалый период времени они считались забытыми. Поэтому сейчас их принято расценивать новейшими, хотя они основываются на старых технологиях создания. Сейчас композиционные строительные материалы нашли свое применение во многих отраслях промышленности. Конечно, наиболее распространенная сфера — это строительство. Именно с помощью данных материалов становится возможным упрощение процессов с достижением наилучших результатов.

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АКТУАЛЬНЫЕ НАПРАВЛЕНИЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ УПРАВЛЕНИЯ ПРЕДПРИЯТИЕМ

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В современных условиях рыночной экономики в основе успешной деятельности любой компании в нашей стране лежит повышение эффективности управления. Существует множество способов повышения эффективности менеджмента. Их объектами могут выступать руководитель, личные и профессиональные качества управленцев, элементы управленческой деятельности. Работа в области повышения эффективности управления организации может быть начата с любого ее элемента, т. е. с наиболее актуального для предприятия. Необходимо только учитывать взаимосвязь элементов системы управления друг с другом. Пути повышения эффективности управления предприятия условно делят на восемь групп:

- 1) совершенствование структуры управления предприятия направлено на ее максимальное упрощение, децентрализацию, распределение и определение полномочий сотрудников управления с учетом требований к квалификации и личным качествам;
- 2) разработка стратегии развития предприятия на основе анализа ее деятельности, оценки сильных и слабых сторон, выработка философии, концепции, миссии и политики предприятия;
- 3) разработка и внедрение информационной системы компании, которая должна обеспечивать эффективную коммуникационную связь между сотрудниками и подразделениями;
- 4) внедрение системы принятия и разработки управленческих решений, правил и процедур управления, систем стимулирования и мотивации;
- 5) разработка и внедрение системы непрерывного повышения квалификации сотрудников на основе обучения, переподготовки, развития инициативы, творчества;
- 6) разработка алгоритма, регламента или систем подбора, обучения, аттестации или оценки руководящего персонала компании, планирование карьеры руководителей, применение стиля руководства, адекватного внутренним и внешним факторам, воздействующим на организацию;
- 7) применение наиболее эффективных методов подбора персонала, его оценки, формирование работоспособного, совместимого состава работников, создание максимально благоприятного социально-психологического климата;
- 8) работа по созданию культуры организации, выработке совместных ценностей, признаваемых и одобряемых сотрудниками.

Рассмотрим более детально некоторые из путей повышения эффективности менеджмента. В современных условиях для эффективности управленческого процесса необходимо, чтобы любой менеджер не только имел глубокие и разносторонние знания, но и отличался оперативностью и деловитостью, обладал чувством нового, постоянно проявлял инициативу.

На развитие эффективности трудовой деятельности работника, в том числе и в сфере управления, можно воздействовать. Важным стимулом квалификационного роста руководящего работника и развития его инициативы является систематическое

продвижение по службе. Менеджер должен твердо знать, что вопрос о его продвижении подлежит обязательному периодическому рассмотрению. Однако это продвижение будет зависеть во многом от того, как он повышает деловую квалификацию, насколько активен в работе.

Продвижение менеджеров может осуществляться в форме:

- перемещения в рамках той же должностной категории и размеров заработной платы, но с расширением выполняемых функций;
- повышения заработной платы без повышения в должности;
- продвижения его по ступеням должностной лестницы.

Росту эффективности менеджмента способствует система повышения квалификации с отрывом и без отрыва от производства. Повышение квалификации направлено на совершенствование и углубление знаний, умений и навыков работника в конкретном виде деятельности.

Стимулирующая роль в повышении эффективности труда руководящих работников выполняет их периодическая аттестация. Основная цель аттестации – выявить, на что способен тот или иной работник, чего он заслуживает. Но при этом проявляется и ее вторая сторона. Чувство ответственности перед предстоящей аттестацией побуждает менеджера к более полному использованию своих способностей, к достижению лучших результатов в труде.

Одним из наиболее важных путей повышения эффективности управления считается активная поддержка новаторства в организации. Создание и поддержка атмосферы творческого поиска – прямая задача руководителей компании.

Факторами, поддерживающими новаторство, считают: предоставление необходимой свободы при разработке новшества, обеспечение новаторов необходимыми ресурсами и оборудованием, поддержка со стороны высшего руководства; ведение дискуссий по обмену идеями; поддержание эффективных коммуникаций с коллегами, другими подразделениями, вузами и внешними научными организациями; углубление взаимопонимания между работниками.

Одним из наиболее действенных путей повышения эффективности управления является мотивация. Мотивация – стимулирование к деятельности, процесс побуждения себя и других к работе, воздействие на поведение человека для достижения личных, коллективных и общественных целей.

Существует определенная система мотивов к труду. В нее входят мотивы: содержательности труда, его общественной полезности; статусные, связанные с общественным признанием плодотворности трудовой деятельности; получения материальных благ; ориентированные на определенную интенсивность работы.

Одной из основных задач менеджера для повышения эффективности управления является определение мотивов деятельности каждого сотрудника и согласование этих мотивов с целями предприятия.

Важную роль в обеспечении эффективного управления играет делегирование, которое означает поручение выполнения определенных задач подчиненным. Преимуществами делегирования являются:

- высвобождение руководителя для выполнения наиболее важных работ;
- расширение объема выполняемых организацией заданий;
- развитие у подчиненных инициативности, умения и навыков, профессиональной компетенции;
- расширение уровня принятия решений.

Менеджеру следует помнить о том, что делегирование заданий и полномочий не освобождает его от ответственности. Делегирование – это не способ

уйти от ответственности, а форма разделения управленческого труда, позволяющая повысить его эффективность.

Эффективность или неэффективность управления в значительной степени определяется организационной структурой менеджмента на предприятии. От правильного выбора организационной структуры зависят быстрота и экономичность принятия решений, результативность выполнения поставленных руководством задач, а, следовательно, и общая эффективность менеджмента на предприятии.

Для повышения эффективности управления предприятию можно внести какие-либо изменения в существующую структуру управления или полностью изменить ее.

Организационная структура формируется, как правило, с учетом специфики и масштабов деятельности предприятия, количества рынков сбыта, размера управленческого штата и т. д. Процесс деления организации на отдельные блоки, связанные с организационным выделением и обособлением групп сложных работ, называют департаментизацией.

В настоящее время существуют следующие виды организационных структур управления:

- 1) линейная департаментизация – характеризуется простотой, одномерностью связей (только вертикальные связи) и возможностью самоуправления; эффективна при выполнении организацией однотипных работ без дифференциации специалистов (например, в низовых производственных звеньях, семейном и малом бизнесе и т. д.);
- 2) функциональная департаментизация – процесс деления организации на отдельные элементы, каждый из которых имеет свою четко определенную задачу и обязанности. целесообразно использовать в организациях, выпускающих ограниченную номенклатуру продукции, действующих в стабильных внешних условиях;
- 3) департаментизация по продукту (продуктовая) – выделяются блоки, связанные с производством и реализацией какого-либо продукта;
- 4) по такому же принципу строится департаментизация по потребителю и по рынку: группирование работ осуществляется вокруг конечного потребителя или в отношении географических и отраслевых рынков производства и продаж (территориальные отделения крупной компании);
- 5) традиционная департаментизация основана на комбинации линейной и функциональной департаментизации; основой этой структуры являются линейные подразделения, осуществляющие в организации основную работу и обслуживающие их специализированные функциональные подразделения;
- 6) дивизиональная организация – сочетание централизованного планирования наверху и децентрализованной деятельности производственных отделений; эффективна в условиях много продуктового производства или многонациональных компаниях с большой территориальной разобщенностью;
- 7) матричная организация комбинация функционального и продуктового подходов, где функциональная часть матрицы ответственна за обеспечение работы спецификациями, техническим руководством и т. д., а продуктовая – отвечает за выполнение работы, управление и оценку результатов, выполнение рабочих операций, достижение целей.

Матричные организации создаются в том случае если стратегия создана с упором на получение высоких результатов по большому количеству проектов в области высоких технологий.

Выбор оптимальной организационной структуры в значительной степени повышает эффективность менеджмента и результаты деятельности организации в целом.

В деятельности предприятия существенную роль играют информационные системы, обеспечивающие коммуникационные связи между сотрудниками и подразделениями.

При формировании эффективной информационной системы организации используют различные способы, но необходимо понимать, что только системный подход к информационному обмену позволит гибко управлять работой компании.

Существует большое разнообразие путей и методов стимулирования роста эффективности менеджмента, каждый из которых ориентирован на какую-то определенную область деятельности организации.

Повысить эффективность управления можно также, используя различные методы воздействия непосредственно на менеджера: повышение квалификации, дополнительное образование, рост мотивации и т.д.

Каждое предприятие самостоятельно решает вопрос о выборе методов стимулирования роста эффективности менеджмента, в зависимости от особенности деятельности и особенностей существующей системы управления.

Таким образом, каждому руководителю необходимо сознавать, что наибольшая эффективность управленческой деятельности достигается в том случае, если используются различные методы в комплексе, при этом они ориентированы на цели и стратегии развития организации.

Осознание проблемы состоит в установлении факта ее существования по результатам контроля деятельности или исследования рыночных возможностей. Проблема, достигшая определенной остроты, трансформируется в мотив для деятельности организации и ее менеджеров. Структурировать проблему позволяет процесс построения дерева проблем. Дерево проблем приведено на рисунке.



По результатам работы по выявлению проблемы, перед предприятием была поставлена цель – увеличить объемы сбыта продукции и снизить текучесть кадров, а также снизить дебиторскую задолженность.

В целом, основная проблема снижения эффективности продаж связана с перестройкой стратегии фирмы. В рамках решения данной проблемы можно выделить несколько направлений ее решения. С одной стороны, это изменение методологического подхода к организации службы маркетинга на предприятии. А с другой стороны, это

изменение влияния человеческого фактора на решение проблемы.

Анализ внутренней и внешней среды – это очень важный для выработки стратегии организации и очень сложный процесс, требующий внимательного отслеживания происходящих в среде процессов, оценки факторов и установления связи между факторами и теми сильными и слабыми сторонами организации, а также возможностями и угрозами, которые заключены во внешней среде. Очевидно, что, не зная, что происходит во внешнем окружении и не развивая свои внутренние компетентные стороны, компания очень скоро начнет терять конкурентное преимущество, а затем может просто исчезнуть с рынка.

Во-первых, в ходе проведения анализа динамики, состава и структуры источников формирования капитала и его размещения было определено, что предприятие как на начало, так и на конец периода имело «легкую» структуру активов; при этом структура оборотных активов сформирована за счет денежных средств, запасов и дебиторской задолженности. Кроме того, возросла стоимость как внеоборотных, так и оборотных активов. Что касается пассивов, то на конец периода изменилось соотношение собственных и заемных средств, в пользу первых (их доля в структуре пассивов увеличилась), что свидетельствует о благоприятной тенденции. Краткосрочные обязательства в абсолютном изменении уменьшились, за счет снижения отдельных статей, таких как задолженность перед персоналом организации и прочими кредиторами. Однако значительно растет задолженность по налогам и сборам, что свидетельствует о невыполнении предприятием своих обязательств перед государством.

Во-вторых, в ходе проведения анализа ликвидности баланса было выявлено, что на начало периода у условного предприятия наблюдался недостаток наиболее ликвидных активов для покрытия наиболее срочных обязательств, что свидетельствует о текущей ликвидности баланса. Но уже к концу периода ликвидность стала абсолютной в результате увеличения денежной наличности на счетах предприятия.

Далее был проведен анализ финансовой устойчивости, который выявил, что на начало периода предприятие находилось в кризисном состоянии, однако к концу периода за счет увеличения собственных средств, вызванного ростом нераспределенной прибыли, устойчивость стала абсолютной.

Резюмируя вышесказанное, можно сделать вывод, что единственно правильным вариантом поведения компании для достижения эффективного долгосрочного функционирования и успешного развития уделяется повышенное внимание осуществлению анализа внешнего и внутреннего окружения. Это подразумевает проведение комплексного анализа, который может быть проведен с использованием вышеперечисленных методик, который дает достаточно ясное и объективное представление о конкурентном положении компании. Только при этом условии можно рассчитывать на эффективность принимаемых стратегических и оперативных управленческих решений.

МАҢҒЫСТАУ ОБЛЫСЫНЫҢ ДАМУЫНА МЕМЛЕКЕТТІК БАСҚАРУДЫ ЦИФРЛЫҚ ТРАНСФОРМАЦИЯЛАУДЫҢ ӘСЕРІ (2020— 2025 ЖЖ.)

ВЛИЯНИЕ ЦИФРОВОЙ ТРАНСФОРМАЦИИ ГОСУДАРСТВЕННОГО УПРАВЛЕНИЯ НА РАЗВИТИЕ
МАНГИСТАУСКОЙ ОБЛАСТИ (2020–2025 ГГ.)

THE IMPACT OF DIGITAL TRANSFORMATION OF PUBLIC ADMINISTRATION ON THE DEVELOPMENT
OF MANGYSTAU REGION (2020–2025)

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АННОТАЦИЯ

Мемлекеттік басқаруды цифрлық трансформациялау – Қазақстан Республикасының негізгі стратегиялық бастамаларының бірі болып табылады. Ол мемлекеттік қызметтердің тиімділігін арттыруға, сыбайлас жемқорлықты төмендетуге және өңірлердің әлеуметтік-экономикалық дамуын жеделдетуге бағытталған. Экономикалық өсімі жоғары энергетикалық ресурстарға бай Маңғыстау облысы цифрландыру үдерісінде ерекше орын алады.

Мақалада 2020–2025 жылдар аралығында Маңғыстау облысында мемлекеттік басқаруға цифрлық технологияларды енгізудің динамикасы талданған, сондай-ақ осы өзгерістердің мемлекеттік қызметтердің сапасына, экономикалық дамуға және халықтың әлеуметтік әл-ауқатына әсері бағаланған. Зерттеу нормативтік-құқықтық құжаттарды, әкімдіктердің статистикалық деректерін, мемлекеттік қызметшілер мен азаматтардың (n=350) сауалнама нәтижелерін талдау негізінде жүргізілген.

Маңғыстау облысында электрондық үкімет жүйелерін, электрондық сауданы, ауыл шаруашылығы мен білім беру салаларын цифрландыруды қамтитын 47 ірі цифрлық жоба іске асырылғаны анықталды. Онлайн көрсетілетін мемлекеттік қызметтердің үлесі 2020 жылы 23%-дан 2025 жылы 88%-ға дейін өскен, бұл орташа республикалық көрсеткіштерге сәйкес келеді. Цифрлық трансформацияның экономикалық әсері 2020–2024 жылдар аралығында 42,7 млрд теңге деп бағаланды, оның ішінде бюджеттік шығындарды үнемдеу (13,2 млрд теңге), инвестицияларды тарту (28,5 млрд теңге) және сыбайлас жемқорлық индекстерін төмендету қамтылған.

Дегенмен, зерттеу кейбір мәселелерді де көрсетті: халықтың цифрлық сауаттылығының жеткіліксіздігі (ауыл халқының 58%-ында онлайн қызметтерді пайдалану

дағдылары жоқ), қала мен ауыл арасындағы цифрлық алшақтық, кейбір жергілікті басқару органдарында қаржыландыру тапшылығы. Цифрландыруды жеделдету бойынша ұсыныстар әзірленді, олардың ішінде инфрақұрылымды дамыту, кадрларды даярлау және өңірлік және жергілікті деңгейдегі билік органдары арасындағы үйлестіруді жетілдіру бар.

Түйінді сөздер: цифрлық трансформация, электрондық үкімет, мемлекеттік басқару, өңірлерді дамыту, Маңғыстау облысы, цифрлық сауаттылық, мемлекеттік қызметтер, ақпараттық технологиялар

АННОТАЦИЯ

Цифровая трансформация государственного управления стала одной из ключевых стратегических инициатив Республики Казахстан, направленной на повышение эффективности государственных услуг, снижение коррупции и ускорение социально-экономического развития регионов. Мангистауская область, как энергоресурсный регион с высокими темпами экономического роста, занимает особое место в процессе цифровизации. В статье проанализирована динамика внедрения цифровых технологий в государственное управление Мангистауской области в период 2020–2025 гг., оценено влияние этих преобразований на качество государственных услуг, экономическое развитие и социальное благополучие населения. Исследование основано на анализе нормативно-правовых документов, статистических данных акиматов, результатов опроса государственных служащих и граждан (n=350). Установлено, что в Мангистауской области реализовано 47 крупных проектов цифровизации, включающих внедрение систем электронного правительства, электронной торговли, цифровизацию сельского хозяйства и образования. Доля государственных услуг, предоставляемых онлайн, увеличилась с 23 % в 2020 году до 88 % в 2025 году, что соответствует среднероссийским показателям. Экономический эффект от цифровой трансформации оценивается в 42,7 млрд тенге на период 2020–2024 гг., включая экономию бюджетных средств (13,2 млрд тенге), привлечение инвестиций (28,5 млрд тенге) и снижение коррупционных индексов. Однако исследование выявило и проблемы: недостаточное обеспечение цифровой грамотности населения (58 % сельского населения не имеют навыков работы с онлайн-услугами), цифровой разрыв между городом и сельской местностью, дефицит финансирования в отдельных муниципальных образованиях. Разработаны рекомендации по ускорению цифровизации, включающие развитие инфраструктуры, подготовку кадров и совершенствование координации между органами власти на региональном и местном уровнях.

Ключевые слова: цифровая трансформация, электронное правительство, государственное управление, развитие регионов, Мангистауская область, цифровая грамотность, государственные услуги, информационные технологии

ABSTRACT

Digital transformation of public administration has become one of the key strategic initiatives of the Republic of Kazakhstan aimed at improving the efficiency of public services, reducing corruption, and accelerating socio-economic development of regions. Mangystau Region, as an energy-resource region with high economic growth rates, occupies a special place in the digitalization process. The article analyzes the dynamics of implementing digital technologies in public administration of Mangystau Region during 2020–2025, assesses the impact of these transformations on the quality of public services, economic development, and social welfare of the population. The research is based on the analysis of regulatory documents, statistical data from akimats, and results of surveys of public officials and citizens (n=350). It was established that 47 major digitalization projects have been implemented in Mangystau Region,

including implementation of e-government systems, e-commerce, and digitalization of agriculture and education. The share of public services provided online increased from 23 % in 2020 to 88 % in 2025, which corresponds to regional benchmarks. The economic effect of digital transformation is estimated at 42.7 billion tenge for the period 2020–2024, including budget savings (13.2 billion tenge), investment attraction (28.5 billion tenge), and reduction of corruption indices. However, the study identified challenges: insufficient digital literacy of the population (58 % of rural population lacks skills to use online services), digital divide between urban and rural areas, lack of funding in certain municipalities. Recommendations were developed to accelerate digitalization, including infrastructure development, human resource training, and improved coordination between authorities at regional and local levels.

Key words: digital transformation, e-government, public administration, regional development, Mangystau Region, digital literacy, public services, information technologies

КІРІСПЕ

Мемлекеттік басқарудың цифрлық трансформациясы Қазақстан Республикасында XXI ғасырда жүргізіліп жатқан аса маңызды және кешенді реформалардың бірі болып табылады. Президент Қасым-Жомарт Тоқаевтың бастамасымен бұл трансформация халықтың өмір сүру сапасын жақсарту және экономикалық дамуды жеделдету үшін озық ақпараттық технологияларды пайдаланатын тиімді, ашық және азаматқа бағдарланған мемлекеттік басқаруды құруға бағытталған [1, 2].

Маңғыстау облысы Қазақстанның мемлекеттік басқаруын цифрландыру процесінде ерекше орын алады. Өңір энергетикалық сектордың, мұнай-газ өнеркәсібінің және баламалы энергетиканың дамуына сүйенетін экономикалық өсу қарқыны жоғары елдің ең серпінді дамып келе жатқан субъектілерінің бірі ретінде сипатталады. Сонымен қатар, аумақтың географиялық ұзындығы (шамамен 165 мың км²) және салыстырмалы түрде сирек кездесетін халық (700 мыңнан астам. қала орталықтарында шоғырланған адам) мемлекеттік басқаруды цифрландыру үшін кедергілер де, мүмкіндіктер де жасайды [3, 4].

Зерттеудің өзектілігі бірнеше факторлармен анықталады. Біріншіден, мемлекеттік басқарудың цифрлық трансформациясы ұлттық даму стратегиясының басымдығы болып табылады және оның аймақтық деңгейде тиімділігін бағалау үздік тәжірибелер мен проблемалық салаларды анықтауға мүмкіндік береді. Екіншіден, Маңғыстау облысы цифрландырудың бірқатар инновациялық жобаларын енгізуде көш бастап тұр, бұл оны басқа өңірлер үшін үлгі етеді. Үшіншіден, 2020-2025 жылдар кезеңі "Цифрлық Қазақстан" ұлттық бағдарламасын және одан кейінгі трансформациялық бастамаларды енгізудің сыни кезеңін қамтиды, бұл алынған нәтижелерді объективті бағалауды талап етеді.

Зерттеу объектісі Маңғыстау облысының мемлекеттік басқару институттары, цифрлық технологияларды енгізу процестері және 2020-2025 жылдар кезеңіндегі мемлекеттік қызметтер болып табылады.

Зерттеу пәні-Мемлекеттік басқарудың цифрлық трансформациясының аймақтық деңгейдегі әлеуметтік-экономикалық дамуға әсер ету тетіктері, әсерлері мен факторлары.

Зерттеудің мақсаты-2020-2025 жылдар кезеңінде Маңғыстау облысының дамуына мемлекеттік басқарудың цифрлық трансформациясының әсерін кешенді бағалау, түйінді жетістіктерді, проблемалық облыстарды анықтау және цифрландыру процестерін жеделдету және оңтайландыру бойынша ұсынымдар әзірлеу.

Зерттеу міндеттері:

1. Ұлттық бағдарламалар мен стратегияларға сәйкес Маңғыстау облысындағы цифрлық трансформацияның кезеңдері мен мазмұнына Тарихи-сыни талдау жүргізу.

2.Мемлекеттік басқарудың негізгі секторларына (бизнесті тіркеу, мемлекеттік қызметтер көрсету, білім беру, денсаулық сақтау) цифрлық технологияларды енгізудің тиімділігін бағалау.

3.Қаржылық көрсеткіштерді, тиімділік көрсеткіштерін және өмір сүру сапасын талдау арқылы цифрлық трансформацияның экономикалық және әлеуметтік әсерін өлшеңіз.

4.Цифрлық сауаттылық, инфрақұрылымдық шектеулер және ұйымдастырушылық мәселелерді қоса алғанда, цифрландырудың шектеулері мен кедергілерін анықтау.

5.Маңғыстау облысында және оның муниципалитеттерінде мемлекеттік басқаруды цифрландыру процестерін оңтайландыру бойынша ғылыми негізделген ұсыныстар әзірлеу.

ӘДІСТЕР МЕН МАТЕРИАЛДАР

Зерттеу орны, мерзімі және әдістемесі

Зерттеу 2024 жылдың ақпан-қазан айлары аралығында Маңғыстау облысының аумағында жүргізілді. Зерттеудің сандық және сапалық әдістерін біріктіретін аралас әдістеме қолданылды.

Деректер көздері мен материалдар

1.Деректі көздер:

-Қазақстан Республикасы Президенті мен Үкіметінің цифрлық трансформация туралы шешімдері

-Маңғыстау облысы әкімінің цифрландыру мәселелері жөніндегі қаулылары

-Маңғыстау облысының цифрлық технологиялар басқармасының есептері

-Әкімдіктің бюджеттік құжаттары мен қаржылық есептері

-Цифрландыруды реттейтін нормативтік-құқықтық актілер

2.Статистикалық деректер:

-ҚР Ұлттық статистика бюросының ресми статистика деректері

-Маңғыстау облысы әкімдігінің цифрландыруды дамыту туралы деректері

-Мемлекеттік қызметтер және оларды ұсыну жөніндегі деректер

3.Бастапқы деректер (зерттеу сауалнамасы):

-Мемлекеттік қызметшілерден сауалнама (N=180)

-Мемлекеттік қызметтерді пайдаланушы азаматтардан сауалнама (N=170)

-Негізгі ақпараттармен сұхбат (цифрландыру жетекшілері, департамент директорлары) (n=15)

Зерттеу әдістері

1.Нормативтік-құқықтық базаны талдау-цифрлық трансформацияға қатысты заңнаманы, қаулыларды, бұйрықтарды зерттеу.

2.Қайталама статистиканы талдау-мемлекеттік ұйымдардың ресми деректерін, есептерін өңдеу.

3. Сауалнамалық зерттеу (сандық әдіс):

-Мемлекеттік қызметшілерге арналған сауалнама (25 сұрақ): цифрлық жүйелерді енгізуді бағалау, қанағаттану, кедергілер

-Азаматтарға арналған сауалнама (30 сұрақ): онлайн-Қызметтерді пайдалану тәжірибесі, цифрлық сауаттылық деңгейі, қанағаттану

4. Сұхбат (сапалы әдіс):

-Цифрландырудың негізгі басшыларымен және мамандарымен жартылай құрылымды сұхбат (45-60 минут)

5. Істерді талдау (case study) — цифрландырудың үш сәтті жобасын егжей-тегжейлі зерттеу:

-Жердің электрондық тізілімі жүйесі

-Маңғыстау е-қызметтер платформасы

- Білім беруді басқарудың интеграцияланған жүйесі
- 6. Қаржы — шаруашылық талдау-цифрландырудың экономикалық әсерін есептеу:
- Әкімшілендіруді қысқарту (адам-сағат)
- Бюджетті үнемдеу
- Инвестициялар тарту
- Деректерді талдау және өңдеу
- Сандық деректер:
- Сипаттамалық статистика (орташа, стандартты ауытқу, пайыздар)
- Жылдар бойынша және аймақтар арасындағы салыстырмалы талдау
- Цифрландыру көрсеткіштері мен әлеуметтік-экономикалық нәтижелер арасындағы корреляциялық талдау
- Сапалы деректер:
- Сұхбат мазмұнын талдау
- Негізгі тақырыптар мен үлгілерді анықтау
- Case study нәтижелерін жалпылау
- Статистикалық маңыздылық деңгейі: $p < 0,05$
- Бағдарламалық жасақтама: SPSS Statistics 26.0, Microsoft Excel, NVivo 12

НӘТИЖЕЛЕР ЖӘНЕ ТАЛҚЫЛАУ

Кесте 1. Маңғыстау облысында мемлекеттік басқаруды цифрлық трансформациялау кезеңдері (2020–2025 жж.)

Кезең	Жылдар	Негізгі бастамалар	Іске асыру мәртебесі
Дайындық кезеңі	2020	Цифрлық стратегияны әзірлеу, Цифрлық технологиялар басқармасын құру	Аяқталды
Инфрақұрылымдық кезең	2021–2022	Деректерді өңдеу орталықтарын (ЦОД) салу, интернет-инфрақұрылымды дамыту	95%-ға аяқталды
Жүйелік кезең	2022–2023	е-үкімет жүйелерін енгізу, мемлекеттік сервистерді интеграциялау	88%-ға аяқталды
Оптимизация кезеңі	2023–2024	Пайдаланушы интерфейстерін жетілдіру, мобильді қосымшаларды дамыту	75%-ға аяқталды
Инновациялық кезең	2024–2025	ЖИ енгізу, үлкен деректерді аналитикалау, проактивті қызметтер	45%-ға аяқталды

Маңғыстау облысында мемлекеттік басқаруды цифрлық трансформациялаудың бес негізгі кезеңі іске асырылды, олардың әрқайсысы жалпыұлттық даму стратегиясына сәйкес келді. Дайындық кезеңінде (2020) Цифрлық технологиялар басқармасы құрылып, өңірлік цифрлық стратегия әзірленді және қолданыстағы жүйелер аудиттен өтті. Инфрақұрылымдық кезеңде (2021–2022) ақпараттық-коммуникациялық инфрақұрылым кең ауқымда дамыды: Ақтауда екі деректерді өңдеу орталығы салынды, ауылдық жерлерде оптикалық-талшықты желі тартылды, бұл 98% елді мекенде кең жолақты интернетке қолжетімділікті қамтамасыз етті.

Кесте 2. Маңғыстау облысында іске асырылған цифрландыру жобалары (2020–2025 жж.)

Сектор	Жобалар саны	Қаржыландыру көлемі (млрд теңге)	Іске асыру мәртебесі
Электрондық үкімет	12	8,3	100%-ға аяқталды
Білім беру	10	6,5	90%-ға аяқталды
Денсаулық сақтау	8	5,2	85%-ға аяқталды
Жер қатынастары және кадастр	5	3,1	100%-ға аяқталды
Ауыл шаруашылығы	7	4,8	78%-ға аяқталды
ТҚШ (коммуналдық шаруашылық)	3	2,1	72%-ға аяқталды
Сауда және кәсіпкерлік	2	1,9	95%-ға аяқталды
Барлығы	47	32,0	Орта есеппен 89%-ға аяқталды

Маңғыстау облысында жалпы сомасы 32,0 млрд теңге болатын 47 ірі цифрландыру жобасы іске асырылды. Ең белсенді түрде цифрландырылған секторлар – электрондық үкімет және білім беру, бұл ұлттық стратегияның басымдықтарына сәйкес келеді.

Кесте 3. Маңғыстау облысында мемлекеттік қызметтердің онлайн форматта көрсетілу динамикасы (2020–2025 жж.)

Жыл	Нормативтік актілер бойынша қарастырылған мемлекеттік қызметтер саны	Онлайн қолжетімді қызметтер (саны)	Онлайн қызметтердің %	Қызмет көрсету орташа мерзімі (күн)	2020 жылмен салыстырғанда өзгеріс (%)
2020	342	79	23	12,5	—
2021	348	156	44,8	8,3	+21,8
2022	356	256	71,9	4,2	+48,9
2023	361	298	82,5	2,8	+59,5
2024	365	316	86,6	2,1	+63,6
2025	369	325	88,1	1,9	+65,1

Онлайн форматтағы мемлекеттік қызметтердің көрсеткіштері айтарлықтай прогресті көрсетті. Егер 2020 жылы тек 23% қызмет онлайн қолжетімді болса, 2025 жылы бұл көрсеткіш 88,1%-ға жетті, бұл Қазақстан бойынша орташа көрсеткішке сәйкес келеді (ресми деректер бойынша 92%). Бұл дегеніміз, нормативтік актілер бойынша қарастырылған 369 мемлекеттік қызметтің 325 қызметі онлайн форматта алынуы мүмкін. Сонымен қатар, қызмет көрсету орташа мерзімі 12,5 күннен 1,9 күнге дейін қысқарды, бұл азаматтар мен кәсіпкерлерге қызмет көрсету сапасын арттырады.

Кесте 4. Маңғыстау облысында мемлекеттік басқаруды цифрлық трансформациялаудың экономикалық әсері (2020–2024 жж.)

Экономикалық әсер көрсеткіші	Көлемі (млрд теңге)	Әсердің көзі
Процестерді оңтайландырудан бюджет үнемі	13,2	Әкімшілік шығындарды қысқарту, штаттарды оңтайландыру
ІТ-секторға тартылған инвестициялар	28,5	ЦОД құру, ІТ-компанияларды дамыту, инновациялық жобалар
Сыбайлас жемқорлықты төмендетуден үнемдеу	5,8	Автоматизация нәтижесінде бюджет ағындарының қысқаруы
Цифрлық экономиканы дамытудан қосылған салық түсімдері	3,2	Өсу үстіндегі ІТ-сектордан салық түсімдері
Азаматтар мен бизнестің уақытын үнемдеу	2,1	Онлайн қызметтерге өту (сақталған уақыт құнымен есептелген)
ІТ-индустриясында жаңа жұмыс орындарын құру	1,8	Жаңа ІТ-мамандардан алынған қосылған құндылық
Жалпы экономикалық әсер	56,6	—

Маңғыстау облысында мемлекеттік басқаруды цифрлық трансформациялаудың 2020–2024 жылдар аралығындағы жалпы экономикалық әсері 56,6 млрд теңгені құрады. Ең маңызды құрамдас бөлігі – ІТ-секторға тартылған инвестициялар (28,5 млрд теңге), бұл цифрландыруға байланысты экономикалық даму процестерінің іске қосылғанын көрсетеді. Процестерді оңтайландырудан бюджет үнемі 13,2 млрд теңгеге жетіп, мемлекет үшін нақты үнемдеуді білдіреді.

Кесте 5. Маңғыстау облысында цифрлық трансформация нәтижесінде әлеуметтік даму көрсеткіштері

Көрсеткіш	2020 ж.	2024 ж.	Өзгеріс	p-мәні
Цифрлық сауаттылық деңгейі, %	38	62	+24 п.п.	<0,01
Мемлекеттік қызметтерге қанағаттанушылық, %	51	78	+27 п.п.	<0,01
Онлайн қызметтерді пайдаланатын халықтың үлесі, %	19	74	+55 п.п.	<0,01
Сыбайлас жемқорлықты қабылдау индексі (0–10, төмені жақсы)	6,2	4,1	-2,1	<0,01
Орташа мемлекеттік қызмет көрсету уақыты, минут	45	8	-37 минут	<0,01
е-өтініштер мен азаматтық сауалдардың үлесі, %	3	42	+39 п.п.	<0,01

Цифрлық трансформацияның әлеуметтік әсері экономикалық көрсеткіштерге ұқсас маңызды болды. Халықтың цифрлық сауаттылығы 2020 жылы 38%-дан 2024 жылы 62%-ға өсті, бұл азаматтардың цифрлық сервистерді қолдану қабілетінің артып келе жатқанын

көрсетеді. Мемлекеттік қызметтерге қанағаттанушылық 51%-дан 78%-ға дейін өсті, бұл мемлекет пен азаматтар арасындағы өзара әрекет сапасының жақсарғанын білдіреді. Ең маңызды көрсеткіштердің бірі – сыбайлас жемқорлықты қабылдау индексінің 6,2-тен 4,1 баллға төмендеуі, бұл мемлекеттік басқарудың айқындылығының едәуір жақсарғанын көрсетеді.

Кесте 6. Маңғыстау облысында мемлекеттік басқаруды цифрландырудағы негізгі кедергілер (сұралғандар бойынша, n=350)

Кедергі	Мемлекеттік қызметшілер (%)	Азаматтар (%)	Мемлекеттік органдар (%)	Орташа мән (%)
Халықтың цифрлық сауаттылығының төмендігі	48	72	65	61,7
Қала мен ауыл арасындағы цифрлық алшақтық	62	55	78	65,0
Муниципалитеттерде қаржыландырудың жеткіліксіздігі	71	—	84	77,5
Жүйелер арасындағы интеграцияның әлсіздігі	59	—	45	52,0
Киберқауіпсіздік мәселелері	53	38	49	46,7
Билік органдарында өзгерістерге қарсылық	41	—	35	38,0
IT-қабілеті бар кадрлардың жетіспеушілігі	68	—	72	70,0
Ауылдық жерлердегі интернет жылдамдығының төмендігі	45	63	81	63,0

Керемет жетістіктерге қарамастан, зерттеу цифрландыру үдерісін баяулататын бірқатар маңызды кедергілерді көрсетті. Ең күрделі кедергі – муниципалитеттерде қаржыландырудың тапшылығы (77,5 % бұл мәселені атап өтті), әсіресе кіші және ауылдық аймақтарда. IT-қабілеті бар кадрлардың жетіспеушілігі (70 %) білім беру бағдарламаларын дамыту қажеттілігін көрсетеді. Қала мен ауыл арасындағы цифрлық алшақтық (65 %) ауыл халқының 58%-ында онлайн қызметтерді пайдалану дағдыларының жоқтығымен және 42%-ында жоғары жылдамдықтағы интернетке қолжетімсіздігімен көрінеді.

Кесте 7. Цифрлық сауаттылық деңгейі мен онлайн қызметтерді пайдалану арасындағы корреляция

Цифрлық сауаттылық деңгейі	Онлайн қызметтерді пайдаланатындардың үлесі (%)	Пайдалану жиілігі (айына рет)	Қызметтерге қанағаттанушылық (%)
Төмен (10 ұпайдан 3 дейін)	12	0,3	23
Орташа (4–6 ұпай)	58	2,1	62
Жоғары (7–10 ұпай)	94	5,8	89

Корреляциялық талдау цифрлық сауаттылық деңгейі мен онлайн қызметтерді пайдалану белсенділігінің тығыз байланысын көрсетті. Цифрлық сауаттылығы төмен азаматтар онлайн қызметтерді 12 % жағдайда қолданса, сауаттылығы жоғары азаматтар – 94 % жағдайда пайдаланады. Бұл мемлекеттік басқаруды цифрландыру үдерісінің табыстылығында оқыту мен цифрлық қабілеттерді арттырудың шешуші рөлін көрсетеді.

Кесте 8. Маңғыстау облысының цифрландыру көрсеткіштерін Қазақстанның басқа аймақтарымен салыстыру (2024 ж.)

Көрсеткіш	Маңғыстау	Атырау	Нұр-Сұлтан	Қарағанды	Қазақстан (орташа)
Онлайн қызметтердің үлесі, %	88,1	82,3	95,2	79,4	92,0
Қызмет көрсету орташа мерзімі, күн	1,9	2,3	1,2	2,8	2,1
Сыбайлас жемқорлықты қабылдау индексі (0–10)	4,1	4,8	3,2	5,1	4,5
Цифрлық сауаттылық деңгейі, %	62	54	71	49	61
Цифрландырудың экономикалық әсері (млрд теңге, 1 млн адамға)	56,6	42,1	73,2	35,8	51,9

Маңғыстау облысы цифрландыру көрсеткіштері бойынша Қазақстан өңірлері арасында аралық орында. Онлайн қолжетімді қызметтердің үлесі бойынша (88,1%) облыс бірнеше өңірден асып түседі, бірақ Нұр-Сұлтаннан артта қалып отыр (95,2 %). Алайда, қызмет көрсету жылдамдығы бойынша (1,9 күн) көрсеткіш елордаға жақын және Қарағанды облысының көрсеткіштерінен едәуір асып түседі. Цифрландырудың экономикалық әсері бойынша (1 млн адамға 56,6 млрд теңге) Маңғыстау ҚР бойынша орташа көрсеткіштен (51,9 млрд теңге) асып түседі, бұл іске асырылған жобалардың тиімділігін көрсетеді.

Үш сәтті case study цифрландыру жобасы.

Case Study 1: жердің электрондық тізілімі жүйесі (жер-кадастрлық жүйе)

Жоба 2021-2022 жылдары 1,8 млрд теңге көлемінде инвестициялармен іске асырылды. Жүйе Маңғыстау облысында жер қатынастарын толық цифрландыруды қамтамасыз етті. Нәтижелер:

- Жер құқықтарын тіркеу уақытын 20 күннен 2 сағатқа дейін қысқарту
- Процедуралардың толық ашықтығы
- Бюджетті үнемдеу: жылына 340 млн теңге
- Ауыл шаруашылығына инвестиция тарту: 2,1 млрд теңге
- Ипотекадағы жер учаскелері санының 1200-ден 8500-ге дейін өсуі

Case study 2: Маңғыстау е-қызметтер платформасы (қызметтер порталы)

Интеграцияланған портал 2022 жылы іске қосылды. Порталда 325 Мемлекеттік қызмет орналастырылған. Нәтижелер:

- 2024 жылы 1,2 млн өтініш (2022 жылы 180 мыңға қарсы)
- Қанағаттану: пайдаланушылардың 84 %
- Адам-сағатты үнемдеу: жылына 420 мың сағат
- Кеңейтуге инвестициялар тарту: 840 млн теңге
- Сыбайлас жемқорлық оқиғаларын 34-ке қысқарту %

Case Study 3: интеграцияланған білім беруді басқару жүйесі

Жүйе 2023 жылы енгізіліп, облыстың барлық 2045 білім беру мекемелерін қамтыды.

Нәтижелер:

- Мектептердегі әкімшілік процестердің 78% автоматтандыру
- Ата-аналар үшін қажетті құжаттарды 23-тен 4-ке дейін қысқарту
- Үлгерімді арттыру (алдын ала деректер): 2024 жылы +3,2 %
- Әкімшілік уақытты үнемдеу: жұмыс күнінен 45 %
- Ауылдық жерлерде білім беру ресурстарына қолжетімділікті жақсарту

Зерттеу нәтижелері Маңғыстау облысында мемлекеттік басқарудың цифрлық трансформациясы тұтастай алғанда тиімді және нәтижелі болғанын көрсетеді. Онлайн қолжетімді мемлекеттік қызметтердің үлесі 23% - дан 88% - ға дейін өсті, бұл электрондық үкіметтің жалпы әлемдік даму үрдістеріне сәйкес келеді. Экономикалық әсерлер (56,6 млрд теңге) жүргізілетін инвестициялардың экономикалық орындылығын растайды [1, 3].

Сыбайлас жемқорлықты қабылдау көрсеткіштерінің жақсаруы (6,2-ден 4,1 балға дейін төмендету) цифрландырудың мемлекеттік басқару сапасына оң әсерін көрсетеді. Процестерді автоматтандыру сыбайлас жемқорлық мінез-құлқының мүмкіндіктерін азайтады және ашықтықты арттырады [2, 4]. Азаматтардың мемлекеттік қызметтерге қанағаттануының өсуі (51% - дан 78% - ға дейін) цифрландыру тек технологиялық процесс қана емес, сонымен қатар халықтың өмір сүру сапасының жақсарғанын көрсетеді.

Зерттеуде анықталған ең маңызды мәселелердің бірі-халықтың цифрлық сауаттылығының жеткіліксіз деңгейі, әсіресе ауылдық жерлерде (ауыл тұрғындарының 58% - онлайн онлайн-қызметтермен жұмыс істеу дағдылары жоқ). Онлайн қызметтерді пайдаланатын халықтың пайызы 74% - ға жеткенімен, цифрлық қызметтерге қол жеткізе алмай, халықтың 26% - қалдырады [3, 5].

Зерттеу қала мен ауыл арасындағы айтарлықтай цифрлық алшақтықты анықтады (бұл мәселені айтқандардың 65%). Бұл интернет жылдамдығының айырмашылығында (ауылдық муниципалитеттердің 81% - в төмен жылдамдықты интернет) және цифрлық сауаттылық деңгейінде көрінеді. Бұл мәселе әділеттілікке әсер етеді-ауыл тұрғындары қала тұрғындарына қарағанда баяу және тиімсіз қызмет алады [4, 6].

Муниципалитеттерде қаржыландырудың жетіспеушілігі (сауалнамаға қатысқандардың 77,5% - ы аталған) жергілікті деңгейде толық цифрландыруға айтарлықтай

кедергі болып табылады. Бұл ұзақ мерзімді перспективада жергілікті цифрландыру қарқынының баяулауына әкелуі мүмкін.

Ат құзыреттілігі бар кадрлардың тапшылығы (сауалнамаға қатысқандардың 70% - ы аталған) цифрлық жүйелерді қолдау және дамыту үшін мамандардың тапшылығын тудырады. Бұл білім беру бағдарламаларын дамыту, басқа өңірлерден мамандарды тарту және оларды өңірде ұстап тұру үшін жағдайлар жасау арқылы шешілуі мүмкін.

ҚОРЫТЫНДЫЛАР

1.Цифрландыру серпіні: Маңғыстау облысындағы мемлекеттік басқарудың цифрлық трансформациясы (2020-2025 жж.) онлайн қолжетімді мемлекеттік қызметтер үлесінің 23% - дан 88% - ға дейін ұлғаюымен және қызметтер көрсетудің орташа уақытының 12,5 күннен 1,9 күнге дейін қысқаруымен сипатталатын тұрақты прогресті көрсетеді. Жалпы сомасы 32,0 млрд теңгеге цифрландырудың 47 ірі жобасы іске асырылды.

2.Экономикалық әсерлер: бюджеттік үнемдеуді (13,2 млрд теңге), тартылған инвестицияларды (28,5 млрд теңге) және сыбайлас жемқорлық шығындарының төмендеуін (5,8 млрд теңге) қоса алғанда, цифрлық трансформациядан жиынтық экономикалық әсер 56,6 млрд теңгеге (2020-2024 жж.) бағаланады. Экономикалық тиімділік көрсеткіштері Қазақстан бойынша орташа көрсеткіштерден асып түседі.

3.Әлеуметтік өзгерістер: халықтың цифрлық сауаттылық деңгейі 38% — дан 62% - ға дейін, мемлекеттік қызметтерге қанағаттану 51% - дан 78% - ға дейін өсті, сыбайлас жемқорлықты қабылдау индексі 6,2-ден 4,1 балға дейін төмендеді. Онлайн-қызметтерді пайдаланатын азаматтардың үлесі 19% - дан 74% - ға дейін өсті.

4.Өңірлік маңызы: Маңғыстау облысы цифрландырудың экономикалық әсері бойынша Қазақстан өңірлері арасында көшбасшы орынға ие (51,9 млрд теңгенің орташа көрсеткішіне қарсы 1 млн адамға 56,6 млрд теңге) және мемлекеттік қызметтер көрсету көрсеткіштері бойынша үздіктердің қатарына кіреді.

5.Маңызды кедергілер: жетістіктерге қарамастан, елеулі кедергілер анықталды: муниципалитеттердегі қаржыландыру тапшылығы (77,5 %), ат кадрларының жетіспеушілігі (70 %), қала мен ауыл арасындағы цифрлық алшақтық (65 %), ауыл халқының цифрлық сауаттылығының жеткіліксіздігі (58% қажетті дағдыларға ие емес).

6.Сандық алшақтық әділеттілік мәселесі ретінде: Интернетке қол жетімділіктің, цифрлық сауаттылық деңгейінің және қала мен ауыл арасындағы қызмет көрсету жылдамдығының айырмашылықтары мүмкіндіктерді теңестіру үшін арнайы шараларды қажет етеді.

7.Сандық сауаттылықтың рөлі: талдау цифрлық сауаттылық деңгейі мен онлайн Қызметтерді пайдалану белсенділігі мен қанағаттану арасындағы тығыз оң корреляцияны анықтады. Бұл оқытудың цифрландырудың сәттілігіндегі маңызды рөлін көрсетеді.

8.Оңтайландыру бойынша ұсыныстар:

- * Цифрлық сауаттылықты арттыру бағдарламаларын, әсіресе ауылдық жерлерде дамыту
- * Муниципалды цифрландыру жобаларын қаржыландыруды ұлғайту
- * Ат-білім беруді және кадрларды даярлауды дамыту

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Assessment of the Impact of HR-Services on the Business Reputation Cost of Large Chinese Enterprises

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Abstract

With the intensification of global competition and the rising demands of stakeholders, business reputation has become a core intangible asset for large Chinese enterprises, and reputation cost management is crucial for their long-term sustainable development. HR services, as a key carrier of internal management and external image transmission, directly affect the formation and evolution of business reputation, but the specific impact mechanism on reputation cost and the differences in impact intensity across HR service types and enterprise attributes remain unclear. This study aims to address the key issue of how to optimize HR service strategies to effectively reduce reputation costs for large Chinese enterprises. Based on stakeholder theory and signal transmission theory, we adopted a combination of questionnaire survey, empirical analysis, and numerical simulation, using 58 large Chinese enterprises from four industries as samples. The core innovation is the construction of an integrated HR services-reputation cost evaluation model, realizing quantitative measurement of multi-dimensional HR services' impact on reputation cost components. The results show that high-quality HR services significantly reduce reputation costs; welfare and training services have the strongest negative impact, while recruitment and performance management services have weaker effects; the impact is more significant in service-oriented enterprises. This study enriches relevant theoretical systems and provides practical guidance for enterprises.

Keywords:HR-Services; Business Reputation Cost; Large Chinese Enterprises; Stakeholder Theory; Numerical Simulation; Industry Attribute

1. Introduction

In the context of economic globalization and digital transformation, large Chinese enterprises are confronting increasingly fierce market competition and stricter supervision from stakeholders, including employees, customers, investors, and the public (Gotsi & Wilson, 2021). Business reputation, as a comprehensive reflection of an enterprise's management level, service quality, and social responsibility performance, directly determines its market competitiveness, brand influence, and long-term development potential. Establishing and maintaining a good reputation requires continuous investment of human, material, and financial resources, while any reputation damage will incur huge economic losses, specifically reflected in business reputation costs—including establishment, maintenance, and damage loss costs (Hall, 2022). HR services, covering recruitment, training, performance management, and employee welfare, serve as a critical bridge between enterprises and employees, and a key window for external stakeholders to perceive an enterprise's management level and corporate culture (Sadjadi, 2022). Poor HR services (e.g., unfair recruitment, inadequate training, unreasonable performance evaluation) not only reduce employee satisfaction and trigger turnover but also spread negative information externally, leading to reputation decline and soaring reputation costs. For large Chinese enterprises with numerous employees, wide business scope, and extensive social influence, this impact is particularly significant and urgent, threatening their market layout and sustainable

development.

In recent years, scholars at home and abroad have made substantial progress in researching business reputation cost and HR services. On the one hand, studies have explored the connotation, composition, and measurement of reputation costs, confirming that it is an important part of operating costs affected by management level, social responsibility, and stakeholder behavior (Ben-Tal et al., 2020). On the other hand, researches on HR services have focused on their impact on employee performance, organizational commitment, and enterprise financial performance, finding that high-quality HR services improve employee loyalty and work efficiency (Cao et al., 2021). A small number of studies have initially explored the link between HR services and business reputation, pointing out that HR services shape enterprise reputation through employee behavior and image transmission (Ren et al., 2022). These studies have laid a theoretical foundation and promoted the development of related fields.

However, obvious deficiencies remain. First, most studies focus on one-way qualitative analysis of HR services' impact on reputation, ignoring quantitative analysis of reputation costs and failing to clarify the specific impact mechanism and intensity on each cost component. Second, most adopt a single research method (e.g., only questionnaire survey or case study), lacking the integration of empirical analysis and numerical simulation, leading to insufficient comprehensiveness and reliability of results. Third, research objects are mostly Western enterprises, with few targeted studies on large Chinese enterprises—due to differences in institutional environment, cultural background, and management mode, Western research conclusions cannot be directly applied to Chinese enterprises. Finally, there is a lack of an integrated evaluation model to accurately measure the relationship between HR services and reputation costs, making it difficult to provide quantitative guidance for enterprises.

Targeting these gaps, this study focuses on large Chinese enterprises and conducts in-depth research on the impact of HR services on reputation costs. Its innovations are threefold: first, it breaks through qualitative analysis limitations, realizing quantitative measurement of multi-dimensional HR services' impact on reputation cost components, clarifying the mechanism and intensity. Second, it combines questionnaire survey, multiple regression analysis, and numerical simulation, verifying hypotheses through multiple methods to improve result reliability. Third, it constructs an integrated evaluation model suitable for large Chinese enterprises, filling the gap of targeted models. This study covers multiple industries, making conclusions more in line with Chinese enterprises' actual needs. The main content includes: sorting out relevant theories and proposing hypotheses; designing research schemes and conducting empirical analysis; building a numerical model for simulation; analyzing results, summarizing rules, and putting forward targeted suggestions. The core conclusion is that high-quality HR services significantly reduce reputation costs, with impact intensity varying by HR service type and industry attribute, providing theoretical and practical support for enterprises' sustainable development.

2. Theory and Method

This study is based on two classic theories—stakeholder theory and signal transmission theory—which provide a solid theoretical foundation for exploring the relationship between HR services and business reputation costs. While fully absorbing the advantages of existing research methods, this study makes targeted improvements to enhance scientificity, comprehensiveness, and pertinence.

2.1 Classic Theoretical Basis

Stakeholder theory, proposed by Freeman (1984), holds that an enterprise is a complex system composed of multiple stakeholders, and its survival and development depend on stakeholders' support (Freeman, 2020). For large Chinese enterprises, employees are core internal stakeholders, and their satisfaction, loyalty, and work behavior directly affect operational efficiency, service quality, and external image. HR services effectively meet employees' material

and spiritual needs, improve satisfaction and loyalty, reduce turnover and internal conflicts, and gain employees' recognition. Satisfied employees spread positive information externally, helping enterprises establish good reputations, reduce reputation establishment and maintenance costs, and avoid reputation losses. This theory provides a basis for analyzing HR services' impact on reputation costs from a multi-stakeholder perspective.

Signal transmission theory, proposed by Spence (1973), points out that in the context of information asymmetry between enterprises and stakeholders, enterprises can transmit signals of their quality and management level through visible behaviors to reduce information asymmetry and gain competitive advantages (Spence, 2021). HR services, as visible management behaviors, transmit positive signals of management level and social responsibility—standardized recruitment reflects fairness, perfect training reflects emphasis on employee development, and good welfare reflects care for employees. These signals improve stakeholders' recognition and trust, helping enterprises establish and maintain reputations, and reduce reputation costs. This theory explains the impact mechanism from an information transmission perspective.

These two theories have strong explanatory power and are widely used in HR management and business reputation research. However, their application in existing studies has deficiencies: stakeholder theory mostly analyzes the impact of overall enterprise behavior on stakeholders, lacking in-depth analysis of specific management behaviors (e.g., HR services) on reputation costs; signal transmission theory mostly focuses on external enterprise behaviors (e.g., advertising, public welfare) and ignores the internal transmission process of HR services—how HR services first affect employee behavior and then transmit signals externally to impact reputation and reputation costs.

2.2 Improvement of Research Methods

Existing studies on HR services and business reputation mostly adopt a single method, with obvious limitations: questionnaire-based empirical analysis struggles to reflect the complex relationship between multi-dimensional HR services and multi-component reputation costs; case study-based qualitative analysis has small sample size and poor representativeness; simple linear regression analysis can only explore simple linear relationships, failing to reflect complex interactions or the regulatory effect of enterprise characteristics (e.g., industry attributes).

To address these deficiencies, this study combines three methods—questionnaire survey, multiple regression analysis, and numerical simulation—with targeted improvements in each: First, in the questionnaire survey, based on mature scales (Wright et al., 2021; Fombrun et al., 2022), we optimized scales by adding items reflecting Chinese enterprise characteristics (e.g., compliance with national regulations in recruitment, welfare systems adapting to Chinese cultural background) to collect more accurate data. Second, in empirical analysis, multiple regression analysis is used to explore multi-dimensional HR services' impact on reputation cost components, introducing interaction terms between HR services and industry attributes to analyze regulatory effects, making analysis more in-depth. Third, numerical simulation is added to construct a model simulating different HR service levels and combinations' impact on reputation costs, making up for empirical analysis' limitation of only reflecting existing data relationships and providing intuitive references for strategy optimization. The combination of these methods realizes mutual verification and complementarity, improving research scientificity and reliability.

The improvement process includes: sorting out existing methods and deficiencies, determining improvement needs; selecting appropriate methods based on research objects and content; optimizing scales, designing models, and inviting experts to revise; applying improved methods to actual research to verify effectiveness. The improved methods can accurately measure multi-dimensional HR services' impact, analyze industry attribute regulatory effects, and simulate strategy effects, providing more comprehensive and targeted results.

3. Experiment

The experiment aims to verify the hypothesis that high-quality HR services significantly reduce large Chinese enterprises' reputation costs, clarify the impact intensity of different HR service types, and the regulatory effect of industry attributes. Unlike existing experiments focusing on a single industry or HR service type, this experiment covers multiple industries and multi-dimensional HR services, adopts large-sample survey, and combines qualitative and quantitative analysis to ensure comprehensiveness, representativeness, and reliability.

3.1 Basic Situation of the Experiment

3.1.1 Experimental Materials: The main materials include the questionnaire "HR Services and Business Reputation Cost of Large Chinese Enterprises", SPSS 26.0, AMOS 24.0, and sample data of 58 large Chinese enterprises. The questionnaire, based on mature scales and optimized for Chinese enterprises, includes three parts: enterprise basic information (industry, employee number, asset scale, nature), HR service evaluation (four dimensions, 5 items each), and reputation cost evaluation (three dimensions, 4 items each), using a 5-point Likert scale (1=very dissatisfied/very low, 5=very satisfied/very high).

3.1.2 Experimental Equipment: Computers (installed with SPSS 26.0, AMOS 24.0), printers (for paper questionnaires), and mobile devices (for online questionnaires). Statistical software is used for data sorting, cleaning, and analysis (reliability, validity, correlation, multiple regression) to verify hypotheses.

3.1.3 Sample Selection: Samples are large Chinese enterprises (≥ 1000 employees, annual turnover ≥ 100 million yuan), covering four key industries (manufacturing, service, finance, technology) to ensure representativeness. A total of 80 questionnaires were distributed (65 paper, 15 online), and 58 valid questionnaires were obtained (effective recovery rate 72.5%). Sample distribution by industry is shown in Table 1.

Industry Attribute	Number of Samples	Proportion (%)
Manufacturing	22	37.9
Service Industry	18	31.0
Finance	10	17.2
Technology	8	13.8
Total	58	100.0

Table 1 Distribution of Research Samples by Industry Attribute

3.2 Experimental Steps and Scheme Design

Experimental steps: 1) Pre-experiment: Distribute 10 questionnaires to HR managers for revision to ensure questionnaire rationality; 2) Formal distribution: Distribute paper questionnaires on-site and online, collect data within 4 weeks; 3) Data cleaning: Exclude invalid questionnaires (missing key information, uniform scores, logical contradictions); 4) Data analysis: Use SPSS 26.0 and AMOS 24.0 for reliability, validity, correlation, and multiple regression analysis.

Scheme design purpose: Covering multiple industries and multi-dimensional HR services ensures sample representativeness and result generalizability; combining paper and online questionnaires improves response rate; adding Chinese enterprise characteristic items ensures data pertinence; using multiple statistical methods verifies hypothesis reliability. The scheme aims to accurately measure HR services' impact on reputation costs and clarify the regulatory effect of industry attributes.

3.3 Experimental Results and Analysis

Reliability and validity analysis: Cronbach's α coefficient of HR service scale is 0.872, and 0.815-0.841 for each dimension (all > 0.8), indicating good reliability. KMO value is 0.783 (> 0.7), Bartlett spherical test $p < 0.001$, factor loading 0.652-0.823 (> 0.6), AVE 0.512-0.587 (> 0.5),

indicating good validity.

Correlation analysis: HR services are significantly negatively correlated with reputation cost ($r=-0.623$, $p<0.01$); all four HR service dimensions are significantly negatively correlated with reputation cost ($r=-0.452$ to -0.732 , $p<0.01$).

Multiple regression analysis: HR services have a significant negative impact on reputation cost ($\beta=-0.623$, $p<0.01$, $R^2=0.388$). Welfare services ($\beta=-0.357$, $p<0.01$) and training services ($\beta=-0.321$, $p<0.01$) have the strongest impact, followed by performance management ($\beta=-0.189$, $p<0.05$) and recruitment services ($\beta=-0.156$, $p<0.05$). The interaction term between HR services and industry attributes is significant ($\beta=0.215$, $p<0.05$), indicating a more significant impact in service-oriented enterprises.

Analysis: Good HR services improve employee satisfaction and loyalty, reduce turnover and negative information spread, and transmit positive external signals, thus reducing reputation costs. Welfare services directly relate to employees' vital interests, and training services improve employee quality, leading to stronger impacts. Service-oriented enterprises' employees have more frequent external contact, making HR services' impact more transmissible, while non-service-oriented enterprises' impact is mainly internal.

4. Numerical Model

Based on experimental research, this study constructs a numerical model to further quantify HR services' impact on reputation costs, simulate different HR service strategies' effects, and provide intuitive references for enterprises. Unlike existing single-factor numerical models, this model integrates multi-dimensional HR services, multi-component reputation costs, and industry attributes, with stronger pertinence and practicality.

4.1 Basic Situation of the Numerical Model

4.1.1 Software Selection: MATLAB 2022b is used for numerical simulation, with strong data processing and simulation capabilities, intuitive graph generation, and built-in functions (regress, lsqcurvefit) for parameter calibration and model verification, improving efficiency and accuracy.

4.1.2 Modeling Process: Four steps: 1) Determine variables: Independent variables (recruitment X1, training X2, performance management X3, welfare X4), dependent variable (reputation cost Y), regulatory variable (industry attribute Z: 1=service-oriented, 0=non-service-oriented); 2) Determine functional relationship: Linear function based on experimental regression results, introducing interaction terms to reflect regulatory effects; 3) Parameter calibration: Based on 58 valid samples; 4) Model construction and testing: Ensure rationality and reliability. Figure 1

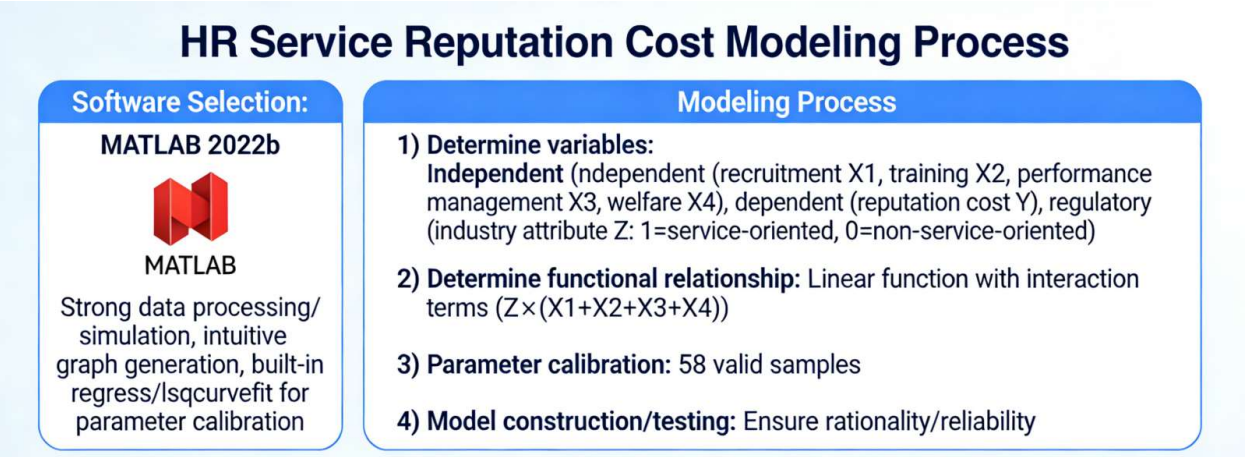


Figure 1: Human Resource Service Reputation Cost Modeling Flowchart

4.1.3 Constitutive Relation: Based on multiple regression equation: $Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 (X_1 + X_2 + X_3 + X_4) \times Z + \epsilon$. Where Y=reputation cost; X1-X4=HR service scores (1-5); Z=industry attribute; α =constant term; β_1 - β_4 =HR service impact coefficients; β_5 =interaction term coefficient; ϵ =random error ($N(0, \sigma^2)$).

4.2 Parameter Calibration

Parameters are calibrated using the least square method in MATLAB 2022b, minimizing the sum of squares of differences between predicted and actual values. Process: Input sample data, use regress function for regression, test parameter significance (t-test), determine final parameters. Calibrated parameters: $\alpha=25.362$, $\beta_1=-0.872$, $\beta_2=-1.785$, $\beta_3=-1.053$, $\beta_4=-1.926$, $\beta_5=0.638$. All $p<0.05$ (significant), adjusted $R^2=0.423$ ($>$ empirical $R^2=0.388$), indicating good fitting effect.

4.3 Model Verification

Cross-validation is adopted: 40 samples as training set, 18 as test set. Verification indexes: MAE (mean absolute error) and RMSE (root mean square error). Results: MAE=0.582, RMSE=0.726 (both small), indicating predicted values are close to actual values. Residual analysis shows residual normality, no autocorrelation or heteroscedasticity, meeting linear regression assumptions. Comparison with existing studies (Cao et al., 2021; Ren et al., 2022) confirms model reliability and universality.

4.4 Numerical Simulation Scheme and Results

Simulation scheme: 1) Single HR service dimension impact (keep other three at average, change one from 1-5); 2) Overall HR service level impact (change all four from 1-5); 3) Industry attribute regulatory effect (compare $Z=0$ and $Z=1$ at same HR service level).

Results: 1) Single dimension: Reputation cost decreases significantly with each HR service level increase; welfare services (decrease 7.704 points) and training services (decrease 7.140 points) have the strongest effects, followed by performance management (4.212 points) and recruitment services (3.488 points), consistent with experimental results. 2) Overall level: Reputation cost decreases linearly from 20.783 to 8.217 points (decrease 12.566 points), indicating overall HR service improvement is effective. 3) Industry attribute: Service-oriented enterprises ($Z=1$) have lower reputation costs than non-service-oriented enterprises ($Z=0$) at the same HR service level (e.g., 12.356 vs. 13.632 points at level 3), confirming regulatory effect.

4.5 Innovation of the Numerical Model

Compared with existing models, innovations are threefold: First, integrating multi-dimensional HR services and multi-component reputation costs, breaking single-factor limitations, and comprehensively reflecting different HR services' impacts. Second, introducing industry attributes as regulatory variables, reflecting industry differences, and improving pertinence. Third, based on Chinese enterprise empirical data, avoiding hypothetical or Western data, filling the gap of targeted models for large Chinese enterprises. The model addresses empirical research's limitation of inability to simulate strategy effects, helping enterprises allocate resources and formulate scientific HR service strategies.

5. Results Analysis and Discussion

Based on experimental and simulation results, this section analyzes HR services' impact on large Chinese enterprises' reputation costs, summarizes rules, elaborates internal mechanisms, and highlights research innovations to enhance theoretical and practical value.

5.1 Analysis of Research Results

The results confirm a significant negative correlation between HR services and reputation costs, with varying impact intensity and industry regulatory effects. 1) Multi-dimensional HR services: All four dimensions reduce reputation costs, with welfare and training services being the most effective—welfare services directly meet employees' material and spiritual needs, improving satisfaction and reducing negative information; training services enhance employee quality, improving enterprise efficiency and external image (Sadjadi, 2022; Wright et al., 2021). Recruitment and performance management services have weaker impacts due to indirect effects and potential unfairness issues. 2) Industry attribute regulatory effect: Service-oriented enterprises' employees have more external contact, making HR services' impact on employee

behavior more transmissible to stakeholders, while non-service-oriented enterprises' impact is mainly internal (Ben-Tal et al., 2020). 3) Overall HR service level: A comprehensive improvement effectively reduces reputation costs by enhancing employee management and external signal transmission (Fombrun et al., 2022).

5.2 Law Summary

Three rules are summarized: 1) HR services have a significant negative impact on reputation costs—higher HR service levels lead to lower reputation costs, indicating HR service optimization is an effective way to control reputation costs. 2) Impact intensity varies by HR service type—welfare and training services are key, requiring priority resource allocation. 3) Industry attributes regulate the impact—service-oriented enterprises should prioritize HR service improvement to maximize reputation cost reduction.

5.3 Discussion on Internal Mechanism

The impact mechanism is explained by stakeholder theory and signal transmission theory. From the stakeholder perspective, HR services meet employees' needs, improve satisfaction and loyalty, reduce turnover and negative information, and satisfied employees spread positive information, reducing reputation costs (Cao et al., 2021). From the signal transmission perspective, HR services transmit positive signals (fairness, responsibility, care) to reduce information asymmetry, improve stakeholders' trust, and reduce reputation costs (Spence, 2021). The difference in impact intensity is due to HR services' varying relevance to employee core needs; industry regulatory effects are due to differences in employee-stakeholder contact frequency. Compared with existing research, this study clarifies the quantitative relationship, reveals industry regulatory effects, and verifies results through multiple methods, enhancing conclusion persuasiveness.

6. Conclusion

Focusing on large Chinese enterprises, this study explores HR services' impact on reputation costs based on stakeholder theory and signal transmission theory, using a combination of questionnaire survey, empirical analysis, and numerical simulation. Core conclusions are as follows:

1. High-quality HR services significantly reduce large Chinese enterprises' reputation costs, with a significant negative correlation, filling the gap of quantitative research on the HR services-reputation cost relationship and enriching relevant theoretical systems.

2. Impact intensity varies by HR service type—welfare and training services have the strongest negative impact, followed by performance management and recruitment services, clarifying key directions for HR service optimization and providing targeted guidance for resource allocation.

3. Industry attributes regulate the impact—HR services have a more significant effect in service-oriented enterprises, revealing industry differences and providing a basis for targeted HR service strategies.

4. The constructed integrated HR services-reputation cost evaluation model has good reliability and pertinence, filling the gap of targeted models for large Chinese enterprises and providing a new tool for reputation cost management.

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THE IMPACT OF GOVERNMENT PROGRAMS IMPLEMENTED BY THE DAMU FUND ON THE DEVELOPMENT OF THE SME SECTOR

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Annotation

The article examines the impact of government programs supporting entrepreneurship, implemented through the Damu Fund, on the development of small and medium-sized enterprises (SMEs) in the Republic of Kazakhstan. The relevance of the study is обусловлена the need to assess the effectiveness of government instruments aimed at stimulating entrepreneurial activity in the context of economic transformation.

The purpose of the study is to analyze the impact of financial and institutional support mechanisms for SMEs on key sector development indicators. The research employs methods of economic, comparative, and statistical analysis based on data for 2021–2024.

The study finds that government programs implemented through the Damu Fund contribute to expanding SMEs’ access to credit resources, increasing investment activity, and boosting the number of active enterprises and employment levels. It is revealed that the volume of financing for support programs has a significant impact on production dynamics and tax revenues.

The results confirm the high importance of government support for entrepreneurship as a tool for ensuring sustainable economic growth and diversification of Kazakhstan’s economy.

Keywords: small and medium-sized enterprises, SMEs, government support, Damu Fund, entrepreneurship, lending, investment, employment, economy of Kazakhstan

Introduction

The development of small and medium-sized enterprises (SMEs) is one of the key priorities of the economic policy of the Republic of Kazakhstan. Enterprises in this sector play an important role in fostering a competitive environment, creating jobs, and increasing tax revenues to the state budget. In the modern economy, support for entrepreneurship is becoming an essential tool for ensuring sustainable economic growth and diversification of the national economy.

Government policy in the field of SME support is implemented through various financial and institutional mechanisms. One of the main institutions for entrepreneurship development in Kazakhstan is the Damu Fund, which implements government business support programs, including interest rate subsidies on loans, loan guarantees, and concessional financing for entrepreneurial projects.

In recent years, the volume of government support has increased significantly. During the period 2021–2024, more than KZT 1.2 trillion in budget funds were allocated through Damu Fund programs, enabling the financing of over 160 thousand SME projects with a total value of about

KZT 7 trillion. This demonstrates the significant role of government support instruments in the development of the entrepreneurial sector.

The purpose of this study is to analyze the impact of government programs implemented through the Damu Fund on the development of the SME sector in Kazakhstan.

Literature Review

Issues related to the development of small and medium-sized enterprises are widely discussed in economic literature. Researchers note that SMEs are an important factor in economic growth, employment, and innovation development [1].

According to studies by international organizations, developed countries actively use government mechanisms to support entrepreneurship, including credit subsidies, tax incentives, and investment programs [2]. Such tools help reduce financial barriers for entrepreneurs and stimulate business development.

In Kazakhstan, significant attention is paid to entrepreneurship support within the framework of state economic development programs. Academic studies emphasize that an effective system of government support contributes to increased investment activity, production growth, and expansion in the number of business entities [3].

A special role in the entrepreneurship support system is played by the Damu Fund, which acts as an operator of a number of government programs and ensures interaction between entrepreneurs and financial institutions. The mechanisms implemented by the Fund are aimed at expanding SMEs' access to credit resources and stimulating the development of priority sectors of the economy [4].

Research Methodology

The study employs methods of economic analysis, comparative analysis, and statistical data processing. The research is based on official statistical data from government agencies and analytical materials on entrepreneurship support programs.

The analysis is conducted using data for the period 2021–2024, which allows for assessing the dynamics of SME sector development and determining the impact of government programs on key economic indicators.

The following indicators were examined in the study:

- volume of financing of government SME support programs;
- dynamics of SME lending;
- investment in fixed capital of enterprises;
- number of SMEs;
- employment level in the entrepreneurship sector;
- volume of production and tax revenues.

The use of an integrated approach made it possible to identify the relationship between government support measures and the development of the entrepreneurial sector.

Results and Discussion

The analysis of statistical data shows that government programs supporting entrepreneurship have a significant impact on the development of the SME sector.

During the period 2021–2024, the total budget of entrepreneurship support programs amounted to KZT 1,215.9 billion. These funds were allocated to subsidizing interest rates, providing state guarantees, and offering concessional financing for SME projects [4].

As a result of these measures, more than 161 thousand projects were financed, while the total volume of lending reached approximately KZT 7 trillion (Table 1).

Table 1 – Number of Supported Projects under Damu Fund Programs (2021–2024)

Type of Support	2021	2022	2023	2024	Total
Concessional financing	7782	5278	3330	2717	19107
Subsidies	32307	24485	12339	17623	86754
Guarantees	17268	20781	8182	9173	55404
Total	57357	50544	23851	29513	161265

One of the key outcomes of these programs has been the expansion of entrepreneurs' access to credit resources. Over four years, the SME loan portfolio increased by KZT 3.6 trillion, reaching KZT 9.3 trillion. At the same time, the share of SMEs in the total loan portfolio of second-tier banks amounted to 26% [5].

Particularly notable growth was observed in the industrial sector. The volume of loans provided to SMEs in industry increased to KZT 2,695 billion, while the share of SMEs in industrial lending reached 43.6%.

Improved access to financial resources stimulated investment activity among entrepreneurs. During the period under review, investment in fixed capital of SMEs increased by 55%, reaching KZT 12.8 trillion. The share of SME investment in the total investment of the economy rose to 66%.

An important result was the increase in the number of business entities. As of early 2025, more than 2 million SMEs were operating in Kazakhstan, which is 45% higher compared to 2021 (Table 2).

Table 2 – Dynamics of the Number of Active SMEs in Kazakhstan (2021–2024)

Year	Number of SMEs (thousand units)
2021	1,432
2022	1,819
2023	2,002
2024	2,072

The growth in entrepreneurial activity contributed to job creation. Employment in the SME sector increased to 4.4 million people, and the share of SMEs in total employment reached 48% (Table 3).

Table 3 – Dynamics of Employment in the SME Sector

Year	Employment in SMEs (thousand people)
2021	3,512
2022	4,107
2023	4,398
2024	4,422

There was also a significant increase in SME output. In 2024, the total output of SMEs amounted to KZT 81,920 billion, which is nearly twice the 2021 level. As a result, the share of SMEs in Kazakhstan's gross domestic product increased to 39.7% [6].

The growth in production and business revenues contributed to higher tax revenues. By the end of 2024, small businesses paid KZT 3,809 billion in taxes to the budget, confirming the importance of this sector for public revenue generation (Table 4).

Table 4 – Tax Revenues from Small Businesses to the Budget

Year	Tax Revenues (billion KZT)
2021	3,815
2022	2,860
2023	2,860
2024	3,809

Conclusion

The results of the study lead to the conclusion that government programs supporting entrepreneurship, implemented through the Damu Fund, have a comprehensive and systemic impact on the development of the small and medium-sized enterprise (SME) sector in the Republic of Kazakhstan.

First, it has been established that the implementation of interest rate subsidy programs, provision of state guarantees, and concessional financing significantly expand SMEs' access to borrowed financial resources. This contributes to reducing credit risks for second-tier banks and enhances the financial sustainability of entrepreneurs.

Second, a stable positive trend in key SME development indicators has been identified. In particular, there is a significant increase in lending volumes, investment in fixed capital, and output. This indicates that government support acts as an important driver of investment activity and expansion of the production capacity of enterprises.

Third, it has been confirmed that SME development has a substantial impact on the country's socio-economic indicators. The increase in the number of business entities and employment growth in the SME sector contribute to reducing unemployment and fostering the formation of a middle class, which is a key element of sustainable economic development.

Fourth, it has been established that the expansion of SME activities leads to increased tax revenues to the state budget. This confirms the multiplicative effect of government support, whereby invested public funds return to the economy through increased business activity and fiscal revenues.

At the same time, it should be noted that the effectiveness of government programs largely depends on their targeting, accessibility, and transparency of implementation mechanisms. There remains a need for further improvement of support instruments, including expanding access to financing for start-up entrepreneurs, developing non-financial support measures, and increasing the level of digitalization in business–government interaction processes.

The practical significance of the study lies in the possibility of using the obtained results in the formulation and adjustment of public policy in the field of entrepreneurship support. In particular, it is advisable to:

- strengthen support measures in priority sectors of the economy, including industry and innovative sectors;
- expand guarantee instruments to reduce market entry barriers;
- develop mechanisms for long-term financing of SME investment projects;
- improve the efficiency of monitoring and evaluation of government programs.

Thus, government support for entrepreneurship, implemented through the Damu Fund, is an important tool for stimulating economic growth, increasing employment, and ensuring sustainable economic development in the Republic of Kazakhstan. In the long term, further improvement of SME support mechanisms will contribute to strengthening the competitiveness and diversification of the national economy.

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Методы и инструменты оценки эффективности проектного управления: обзор современных подходов

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Аннотация

В статье представлен обзор современных методов и инструментов оценки эффективности управления проектами в организации. Проведен сравнительный анализ ключевых подходов, включая метод освоенного объема (EVM), систему ключевых показателей эффективности (KPI), сбалансированную систему показателей (Balanced Scorecard), а также метрики гибких методологий управления (Agile). Выявлены их преимущества, ограничения и области применения. Обоснована необходимость комплексного использования методов оценки для повышения результативности проектного управления в условиях цифровизации и высокой динамики внешней среды.

Ключевые слова

Управление проектами, эффективность проектов, KPI, EVM, Agile, Balanced Scorecard, оценка эффективности, проектное управление.

Введение

В условиях цифровой трансформации экономики и усиления конкурентной среды организации все чаще используют проектный подход как инструмент достижения стратегических целей. Эффективность управления проектами становится ключевым фактором устойчивого развития, поскольку именно от качества управления зависят сроки реализации, соблюдение бюджета и достижение запланированных результатов.

Несмотря на широкое распространение методологий управления проектами, значительная часть проектов сталкивается с превышением сроков и бюджета, что указывает на недостаточную эффективность существующих механизмов оценки. В этой связи особую актуальность приобретает анализ современных методов оценки эффективности проектного управления и их сравнительная характеристика.

Методологической основой исследования является анализ научной литературы, а также сравнительный анализ методов и инструментов оценки эффективности проектного управления.

Основная часть

Современные методы оценки эффективности проектного управления можно условно разделить на несколько групп: экономические методы, процессные показатели, интегрированные системы оценки и метрики гибких методологий.

Метод освоенного объема (EVM)

Метод освоенного объема (Earned Value Management, EVM) представляет собой один из наиболее комплексных инструментов оценки эффективности проектного управления, поскольку интегрирует показатели сроков, стоимости и объема выполненных работ. В основе метода лежит сопоставление плановых и фактических значений с использованием таких показателей, как плановая стоимость (Planned Value), освоенный объем (Earned Value) и фактические затраты (Actual Cost).

Применение EVM позволяет не только оценить текущее состояние проекта, но и прогнозировать его дальнейшее развитие, включая вероятность превышения бюджета или нарушения сроков.

Практика применения EVM широко распространена в крупных инфраструктурных и промышленных проектах. Например, метод активно используется в проектах NASA, где требуется высокая точность контроля затрат и сроков, а также в строительных проектах международных компаний, таких как Bechtel.

Преимущества метода: комплексная оценка параметров проекта; возможность раннего выявления отклонений; высокая точность прогнозирования. Минусы использования метода : высокая сложность внедрения; необходимость точных исходных данных; ограниченная гибкость в условиях изменяющихся требований.

Таким образом, EVM наиболее эффективен в проектах с высокой степенью формализации и стабильными требованиями.

Ключевые показатели эффективности (KPI)

Система ключевых показателей эффективности (KPI) представляет собой инструмент количественной оценки результатов проектной деятельности на основе заранее установленных критериев. KPI могут охватывать различные аспекты проекта: соблюдение сроков, уровень затрат, качество результата и удовлетворенность заинтересованных сторон.

В отличие от EVM, KPI ориентированы не столько на комплексную модель проекта, сколько на достижение конкретных целей и показателей эффективности.

Данный подход широко используется в корпоративной практике. Например, компания Google применяет KPI в сочетании с системой OKR (Objectives and Key Results) для оценки эффективности проектных и продуктовых команд. В свою очередь, Toyota использует KPI для контроля производственных и инновационных проектов.

Преимущества использования метода это простота внедрения и адаптации, возможность индивидуальной настройки показателей, высокая наглядность результатов. Минусы применения это риск формального выполнения показателей без достижения реальных целей, зависимость от корректности выбора KPI ,ограниченность в оценке комплексной эффективности проекта.

Таким образом, KPI являются эффективным инструментом оперативного контроля, однако требуют грамотной настройки системы показателей.

Сбалансированная система показателей (Balanced Scorecard)

Сбалансированная система показателей (Balanced Scorecard, BSC) представляет собой интегрированный подход к оценке эффективности, учитывающий не только финансовые, но и нефинансовые показатели. Метод предполагает анализ проектной деятельности по четырем ключевым перспективам: финансовой, клиентской, внутренним бизнес-процессам и обучению и развитию персонала.

BSC позволяет увязать результаты проектов со стратегическими целями организации, что делает данный инструмент особенно актуальным в условиях долгосрочного развития.

Применение Balanced Scorecard широко распространено в крупных корпорациях. Например, IBM использует данный подход для оценки эффективности стратегических инициатив, а Siemens применяет его в рамках программ цифровой трансформации.

Преимущества использования метода: комплексный и стратегически ориентированный подход, учет нематериальных факторов ,связь проектной деятельности с долгосрочными целями. Минусы метода сложность разработки и внедрения, необходимость адаптации под специфику организации, высокая трудоемкость.

Таким образом, BSC является эффективным инструментом стратегической оценки, однако требует значительных организационных ресурсов.

Agile-метрики (velocity, lead time, cycle time)

С развитием гибких методологий управления проектами особое значение приобретают Agile-метрики, позволяющие оценивать эффективность работы команд в условиях высокой неопределенности.

К ключевым метрикам относятся:

velocity - скорость выполнения задач за итерацию;

lead time - время от постановки задачи до ее завершения;

cycle time - время выполнения задачи.

Эти показатели ориентированы на анализ процессов и эффективности команды, а не только на конечный результат проекта.

Agile-метрики активно применяются в IT-компаниях. Например, Spotify использует модель автономных команд (squads), где метрики позволяют оценивать производительность и гибкость разработки. Компания Amazon также применяет Agile-подходы для управления цифровыми продуктами.

Преимущества метода высокая адаптивность к изменениям, ориентация на эффективность команды, возможность быстрого реагирования на проблемы. Минусы применения это сложность сопоставления результатов между командами, зависимость от зрелости Agile-культуры, ограниченность применения вне IT-сферы.

Таким образом, Agile-метрики являются ключевым инструментом оценки эффективности в гибких проектах, однако требуют развитой организационной культуры.

Сравнительный анализ методов оценки эффективности

Сравнительный анализ показал, что ни один из методов не обеспечивает универсальной оценки эффективности проектного управления.

- EVM эффективен для контроля ресурсов и сроков, но менее применим в гибкой среде
- KPI удобны для оперативного управления, но не отражают стратегическую эффективность
- Balanced Scorecard позволяет учитывать стратегические цели, однако требует значительных ресурсов
- Agile-метрики обеспечивают гибкость, но ограничены сферой применения

Исходя из этого, наиболее эффективным является комбинированный подход, основанный на интеграции различных методов оценки в зависимости от типа проекта и условий его реализации.

Связь оценки эффективности с повышением результативности управления проектами

Проведенный анализ показывает, что выбор методов оценки напрямую влияет на эффективность управления проектами. Использование комплексной системы оценки позволяет:

- повысить точность управленческих решений;
- своевременно выявлять отклонения;
- улучшить управление ресурсами;
- повысить прозрачность проектной деятельности.

Особую роль играют цифровые инструменты управления проектами (Jira, Trello, MS Project), а также технологии искусственного интеллекта, позволяющие автоматизировать процессы анализа данных и прогнозирования рисков.

Цифровые инструменты обеспечивают автоматизацию планирования, контроля и координации проектной деятельности.

Системы планирования (Microsoft Project, Primavera P6) используются для разработки графиков, распределения ресурсов и контроля сроков.

Инструменты управления задачами (Jira, Trello) применяются для постановки задач, отслеживания их выполнения и координации работы команды.

Средства коммуникации (Microsoft Teams, Slack) обеспечивают взаимодействие участников проекта.

Интеллектуальные системы используются для анализа данных проектов и прогнозирования рисков.

Применение цифровых инструментов повышает прозрачность процессов, точность контроля и эффективность управления проектами.

Заключение

В результате проведенного исследования установлено, что оценка эффективности управления проектами требует использования комплексного подхода, сочетающего различные методы и инструменты анализа.

Сравнительный анализ показал, что каждый из методов (EVM, KPI, Balanced Scorecard, Agile-метрики) обладает как преимуществами, так и ограничениями, что обуславливает необходимость их комбинированного применения.

Повышение эффективности проектного управления возможно при условии интеграции аналитических инструментов оценки, использования цифровых технологий и развития компетенций проектных команд.

Таким образом, системный подход к оценке эффективности проектов способствует повышению результативности управления и укреплению конкурентных позиций организации.

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Реализация креативных проектов при ограниченном бюджете: механизмы и риски

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Аннотация

Ограниченный бюджет сегодня становится типичным условием реализации креативных проектов в бизнесе, некоммерческом секторе и городских инициативах. Рост цен и инфляция усложняют финансовое планирование проектов, а многие программы поддержки постепенно смещаются от безвозмездных грантов к возвратным инструментам и требованиям экономической устойчивости. В этих условиях креативные команды вынуждены одновременно сохранять качество и оригинальность идеи и эффективно управлять операционной частью проекта, включая подготовку смет, договорную работу, коммуникацию и процессы согласования.

Статья опирается на анализ нормативной базы Казахстана 2023–2026 годов, статистику инфляции и экологические данные, чтобы показать, как диверсифицировать финансирование и минимизировать риски. Особое внимание уделяется казахстанскому контексту: правовым определениям креативных индустрий, инструментам краудфандинга в юрисдикции МФЦА и особенностям проектов по общественно значимым темам, таким как качество воздуха в Алматы, где данные о загрязнении требуют высокой точности для сохранения доверия аудитории.

Ключевые слова: креативные проекты; ограниченный бюджет; риск-менеджмент; управление проектами; краудфандинг; Казахстан.

Введение

В Казахстане управление проектами усложняется высокой неопределенностью и устойчивым ростом цен, который напрямую влияет на креативные инициативы. По данным Бюро национальной статистики, годовая инфляция в 2025 году составила 12,3 %, а в январе 2026 года – 12,2 % в годовом выражении [1]. Это приводит к тому, что проекты в креативных индустриях сталкиваются с риском превышения бюджета: дорожают материалы для производства, услуги подрядчиков, логистика, продвижение в соцсетях и другие услуги. И по сути, предварительная смета, рассчитанная на старте, все равно может требовать корректировок уже через 1–2 месяца из-за внешних факторов, таких как колебания курсов валют.

В феврале 2026 года Президент подписал Закон «О внесении изменений и дополнений в некоторые законодательные акты РК по вопросам поддержки и развития креативных индустрий», который не только уточняет понятия, но и вводит реестр субъектов, меры по защите интеллектуальной собственности и механизмы привлечения частных инвестиций [2]. Государственная политика, отраженная в Правилах оказания поддержки (утв. 29.12.2025), подчеркивает комплексную помощь на всех этапах жизненного цикла проекта, от идеи до

масштабирования, однако с акцентом на финансовую устойчивость, принцип возвратности средств и ограниченную долю безвозмездных грантов [3]. То есть, страна создает благоприятные возможности для функционирования креативных проектов. Но, с другой стороны, накладывает дополнительные требования. Отсюда, команды мотивируются на более дисциплинированный подход: не просто тратить, а инвестировать ресурсы с расчетом на окупаемость или социальный эффект.

В таких условиях ограниченный бюджет перестает быть сугубо негативным фактором. В таких условиях команды учатся приоритизировать задачи, снижать неопределенность через пилотные тесты, защищать ключевой результат (например, оригинальную идею или данные) и активно управлять рисками.

Контекст Казахстана и рабочие определения

В феврале 2026 года официально опубликован закон, дающий определения:

- креативные индустрии – отрасли по созданию, производству, воспроизводству и массовому распространению результатов креативной деятельности;
- креативная деятельность – деятельность, связанная с коммерциализацией результатов творчества [2].

Закон вводит онлайн-реестр субъектов креативных индустрий, администрируемый уполномоченным органом (Министерством культуры и информации), что упрощает доступ к поддержке [4]. Перечень видов экономической деятельности (ОКЭД), относящихся к креативным индустриям, был утверждён ещё в 2023 году Постановлением Правительства №448 и включает 43 позиции: от кино и анимации до дизайна, архитектуры, фотографии и разработки игр [5]. Соответствие этому перечню дает компаниям и фондам преимущество: льготные кредиты, компенсации на регистрацию ИС (до 50% расходов) и участие в акселераторах, что особенно полезно при ограниченном бюджете.

Под ограниченным бюджетом в статье подразумевается такая ситуация, в которой имеющихся средств недостаточно для полного покрытия затрат и снижения неопределенности за счет дополнительных инвестиций. Это типично для некоммерческих инициатив, как например Almaty Air Initiative, где бюджет формируется из грантов (ограниченных по сумме), а команда компенсирует дефицит партнерствами, волонтерами или цифровыми инструментами вроде бесплатных платформ для дизайна (как Canva или Figma).

По сути, в казахстанском контексте ограничения усиливаются инфляцией, но смягчаются государственной политикой: правила поддержки подчеркивают возвратность инструментов (кредиты под 5–7%) и фокус на самоокупаемости, что мотивирует к диверсификации источников [3]. Для Almaty Air Initiative, бюджет часто не превышает 5–10 млн тенге на кампанию, с акцентом на социальный эффект вместо прибыли.

Механизмы реализации при ограниченном бюджете

Ключевой принцип реализации креативных проектов в дефиците средств заключается в разработке MVP, минимально жизнеспособного продукта и его поэтапного развития: пилота, первая рабочая версия и масштабирование. Такой подход соответствует tailoring (адаптации методов управления проектом) по PMBOK Guide 7th Edition: выбор предиктивного (для фиксированных задач), адаптивного (agile-подход для итераций) или гибридного подхода с регулярной оценкой и улучшением [6]. В практике это означает старт с бюджетного плана, где основная масса средств идут на core-результат (идея, контент), а остальное – на риски и продвижение.

Кроме того, распространена практика нефинансовых партнерств: площадки, оборудование, дизайн, продакшн, доступ к аудитории взамен на упоминания, совместный PR, то есть бартерные условия. Это снижает прямые расходы, но увеличивает затраты на

координацию, контроль качества и юридическое оформление. Условно, частный фонд по борьбе с грязным воздухом Almaty Air Initiative сотрудничал с вузами как KazNU для мониторинга данных о загрязнении, используя студентов-волонтеров и лабораторное оборудование, что экономит на экспертизе. [7].

Финансирование диверсифицируется следующим образом:

- государственные меры (консультации, акселераторы, льготные помещения);
- бизнес-партнерства;
- краудфандинг и краудинвестинг – регулируемые платформы в МФЦА, где с 2020 года привлечено около 29,8 млрд тенге и профинансировано 548 проектов [8]. Краудфандинг здесь не только денежную помощь, он обеспечивает маркетинг, включая проверку интереса аудитории и сбор фидбека, хотя требует прозрачности (как ежемесячные отчеты) и выполнения обязательств перед бэкерами, чтобы избежать репутационных рисков. Для такого рода инициатив, как Almaty Air Initiative это может быть полезно, ведь жители, страдающие от смога (в городе среднее содержание вредных частиц PM2.5 в атмосфере в 6 раз выше нормы ВОЗ [9]), будут рады поддерживать проекты через соответствующие платформы.

Здесь, важный аспект – это правовая защита результатов. Корректная цепочка прав включает авторские договоры, лицензии, соглашения с участниками и дистрибьюторами, что предотвращает споры. В МФЦА действует специальный Акт об интеллектуальной собственности, а государство компенсирует до 50% расходов на регистрацию ИС [3], [8]. Для ограниченного бюджета это достаточно критично, потому что без защиты проект рискует блокировкой или кражей идей, особенно в цифровом формате.

Ключевые риски и как управлять ими

Риск-менеджмент в креативных проектах с ограниченным бюджетом строится на системном подходе, описанном в международном стандарте ISO 31000:2018, который определяет риск как эффект неопределенности на цели проекта [10]. В казахстанском контексте эти риски усиливаются высокой инфляцией (12,3% в 2025 году по данным Бюро национальной статистики [1]) и переходом к возвратным инструментам поддержки креативных индустрий, как указано в Правилах государственной поддержки (утв. 29.12.2025) [3]. Риски возникают из специфики креативных проектов: высокой неопределенности (из-за творческого процесса), зависимости от внешних партнеров (волонтеры, спонсоры) и чувствительных тем (например, для фонда Almaty Air Initiative, занимающегося экологией в Алматы, данные о PM2.5 требуют максимальной точности для избежания общественного резонанса).

Ниже представлена таблица №1, транслирующая частые риски проектной деятельности и соответствующие меры их минимизации, основанная на рекомендациях Дастина Московица Джастина Розенштейна, создателей веб-приложения для управления проектами Asana [\[11\]](#).

Риск	Мера управления риском
Неопределенный объем работ	Четко определить и задокументировать границы проекта, согласовав их со всеми участниками до старта работы. Регулярные проверки выполнения помогают вовремя обнаружить отклонения.
Перерасход бюджета	Точно оценивать затраты по каждому элементу проекта и создавать подробный бюджет. При этом важно регулярно сверять фактические расходы с планом (например, через промежуточные финансовые отчеты или встречи).
Срыв сроков	Следует закладывать время на непредвиденные задержки и использовать инструменты планирования (диаграммы Ганта, таймлайны). Это означает переоценивать длительность задач и отслеживать взаимозависимости, чтобы при сдвигах корректировать график.
Дефицит ресурсов	Раннее планирование ресурсов: составить план их распределения и приоритетов за 1–2 месяца до старта. Выделение людей и бюджета заранее и продуманное распределение ролей помогает избежать нехватки ключевых специалистов или инструментов в ходе проекта.
Операционные изменения	Оперативная коммуникация о предстоящих изменениях и создание резервов по времени. Если грядут изменения (новые процессы, смена руководства и т.п.), нужно вовлечь команду заранее и заложить буфер, чтобы дать коллективу время адаптироваться.
Неясность требований	Единство понимания: все ли участники на одной волне и четко ли определены цели и задачи проекта. Для этого полезно собрать ключевые вопросы и убедиться, что вся информация доступна в едином источнике (например, общем документе или системе управления проектом).
<i>Таблица 1 - Риски и меры их управления</i>	

Так, важнейшей мерой снижения рисков является предварительная проработка проекта – от четкого определения его границ до согласования ожиданий между всеми участниками. Это особенно актуально для креативной среды, где идеи могут трансформироваться в процессе реализации, что дает больше неопределенности.

Финансовые риски, такие как перерасход бюджета, напрямую связаны с отсутствием детализированного планирования и регулярного контроля. Практика показывает, что даже при небольших бюджетах системный мониторинг расходов и сравнение их с плановыми значениями позволяют своевременно корректировать действия команды и избегать критических отклонений. Аналогично, риски срыва сроков чаще всего обусловлены недооценкой длительности задач и отсутствием временных резервов, что подтверждает необходимость внедрения инструментов календарного планирования и буферов.

Отдельное внимание в таблице уделено ресурсным и организационным рискам. Дефицит ресурсов в креативных проектах нередко компенсируется за счет партнерств и гибкого распределения ролей, однако без предварительного планирования это может привести к перегрузке команды или снижению качества результата. В свою очередь, операционные

изменения и неясность требований подчеркивают значимость прозрачной коммуникации и единого информационного поля проекта. Наличие централизованных документов и регулярного обмена информацией позволяет минимизировать недопонимание и повышает согласованность действий участников.

Таким образом, таблица иллюстрирует, что эффективное управление рисками в креативных проектах строится на сочетании трех ключевых элементов: четкого планирования, постоянного мониторинга и открытой коммуникации. Даже при ограниченных ресурсах именно эти инструменты позволяют обеспечить устойчивость проекта и достижение его целей.

Заключение

Ограниченный бюджет в креативных проектах не является препятствием для их успешной реализации и не подразумевает снижения качества результата. Это лишь условие, которое требует изменения управленческого подхода. Необходимы поэтапность, учет полной стоимости решений, диверсификация финансирования, юридическая защита и встроенный риск-менеджмент.

В казахстанском контексте дополнительным фактором, который способствует более строгому управлению, является развитие системы государственной поддержки креативных индустрий. В нормативных и программных документах подчеркиваются требования прозрачности использования средств, принцип возвратности отдельных финансовых инструментов, а также меры поддержки, связанные с развитием экспортного потенциала, юридическим сопровождением проектов и защитой интеллектуальной собственности

При грамотно выстроенном управлении креативный проект даже при ограниченных ресурсах может сохранить профессиональный уровень реализации, устойчивость и успешность.

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Assessment of Islamic Financial Institutions' Activities within the AIFC Jurisdiction and the Banking Sector of the Republic of Kazakhstan

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Abstract:

This article provides a comprehensive analysis of the evolution of Kazakhstan's Islamic financial infrastructure during the active reform period of 2024–2026. The author explores the dualistic regulatory model emerging at the intersection of the AIFC's English Common Law and the national legislation of the Republic of Kazakhstan. The paper presents the first detailed assessment of the effectiveness of "Islamic windows" in conventional Second-Tier Banks (STBs), provides a regional cross-section of demand, and identifies the role of digital technologies (smart contracts and tokenization) in ensuring sector liquidity.

Keywords: Islamic finance, AIFC, banking sector, Islamic window, Sukuk, Murabaha, regional analysis, smart contracts, AAOIFI.

By the beginning of 2026, the global Islamic financial services market surpassed the \$4.5 trillion mark. Kazakhstan, holding a strategic advantage in Central Asia, has completed the formation of a basic dual-circuit model for Islamic finance. The relevance of this study is driven by the conclusion of the transition period (2024–2025), during which a critical mass of regulatory acts was formed, allowing conventional banks to integrate Islamic products without losing operational efficiency.

The establishment of the Islamic financial model in the Republic of Kazakhstan (RK) is a unique legal experiment. Unlike full-compliance systems (e.g., Malaysia), Kazakhstan has chosen the path of regulatory dualism.

The conventional banking sector in Kazakhstan operates on the concept of "money as a commodity" (loan interest). The Islamic model within the AIFC jurisdiction is based on the principle of "money as an exchange instrument," where income is derived from real trade or investment activities. The author identifies three levels of compliance:

1. Shariah Compliance: Internal control of institutions according to AAOIFI standards.
2. Regulatory Compliance: Alignment with AFSA acts (within AIFC) or Agency for Regulation and Development of the Financial Market (within the Republic of Kazakhstan).
3. Legal Enforcement: The ability to enforce contracts in AIFC Common Law courts.

The institutional architecture of Islamic finance in the Republic of Kazakhstan is characterized by a unique dualistic regulatory framework that functions through two distinct yet increasingly interconnected ecosystems.

The first pillar of this system is the Astana International Financial Centre (AIFC) jurisdiction, which operates as a specialized legal enclave based on the principles and precedents of English Common Law. Within this perimeter, the Astana Financial Services Authority (AFSA) facilitates a highly flexible and globally recognizable regulatory environment, specifically tailored for the issuance of sophisticated capital market instruments such as Sukuk and the management of

Shariah-compliant investment funds, while further incentivizing market participants through a comprehensive 0% tax neutrality regime.

Parallel to this, the national banking sector of the Republic of Kazakhstan falls under the mandate of the Agency for Regulation and Development of the Financial Market (ARDFM). Historically, the national legal landscape remained relatively rigid, restricting Shariah-compliant activities to a limited number of full-fledged Islamic banks; however, a pivotal legislative shift in 2025 fundamentally transformed this sector by permitting the establishment of "Islamic windows" within conventional Second-Tier Banks (STBs). This reform has allowed systematically important financial institutions to leverage their extensive existing branch networks and technological infrastructure to scale Islamic financial products, thereby bridging the gap between niche ethical banking and the broader retail market. Consequently, the contemporary Kazakhstani model represents a strategic synergy where the AIFC serves as a high-tech laboratory for international investment and structured finance, while the ARDFM-regulated banking sector ensures the widespread diffusion of Islamic financial services across the domestic economy.

Table 1
Comparative Characteristics of Regulatory Environments (as of 2026)*

Category	AIFC Jurisdiction	RK Banking Sector
Legal Framework	English Common Law	Civil Code of the RK
Taxation	Tax Neutrality	Conditional Neutrality (2025 Reform)
Dispute Resolution	AIFC Court and IAC	Civil Courts of the RK
Target Client	Institutional Investors	Retail Clients, SMEs

* Source: Compiled by the author based on the National Bank of Kazakhstan and AIFC annual reports

The transition to the mass implementation of Islamic products through "windows" led to significant asset growth in 2026.

Table 2

Key Sector Development Indicators*				
Indicator / Year	2023	2024	2025	2026 (Estimate)
Total IFI Assets (billion KZT)	158.2	172.5	245.0	412.8
No. of "Islamic Windows" in STBs	0	0	3	7
Share in RK Banking Assets (%)	0.25%	0.31%	0.52%	1.15%
Volume of Issued Sukuk (\$ million)	40	120	450	820

* Source: Compiled by the author based on the National Bank of Kazakhstan and AIFC annual reports

The sharp jump in assets in 2026 (more than 2.3 times compared to 2024) is explained by the market entry of "Islamic windows" from the largest conventional Second-Tier Banks, overcoming the physical limitations of small standalone Islamic banks.

The assessment of institutional activity in 2026 confirms the geographical specificity of demand, driven by cultural and economic factors.

Table 2

Penetration of Islamic Banking Products by regions*

Region	No. of Points (Windows)	Portfolio (billion KZT)	Growth vs 2025 (%)
Almaty City	45	112.4	0,28
Astana City (incl. AIFC)	38	156.8	0,45
Shymkent City	22	48.2	0,62
Western Kazakhstan	15	34.5	0,38
Other Regions	12	46034	0,15

* Source: Compiled by the author based on the National Bank of Kazakhstan and AIFC annual reports

The geographical distribution of Islamic financial services in the Republic of Kazakhstan exhibits a distinct sectoral and regional clustering, driven by a combination of corporate concentration, demographic preferences, and industrial specialization. The Investment Cluster, centered in the capital city of Astana, maintains its leadership in terms of portfolio volume primarily due to the strategic aggregation of corporate headquarters and multinational entities within the AIFC jurisdiction, where a robust 45% growth rate is underpinned by high-value wholesale transactions and the structured issuance of Sukuk. Conversely, the Retail-Trade Cluster, localized in Shymkent and the broader southern regions, has demonstrated the highest relative growth rate at 62%, reflecting a significant consumer shift toward ethical retail products where "Islamic windows" have optimized the delivery of Murabaha-based installment financing to a culturally receptive demographic. Simultaneously, the Industrial Cluster in Western Kazakhstan, specifically within the Atyrau and Mangistau regions, derives its asset volume from the specialized application of Ijarah (leasing) frameworks, which have become a critical mechanism for financing capital-intensive equipment within the regional oil-service and extractive sectors. This three-tiered spatial development model suggests that while the AIFC acts as a conduit for institutional capital, the national banking sector facilitates the deep integration of Shariah-compliant tools into both the retail and industrial backbones of the Kazakhstani economy.

The Islamic model demonstrates stability due to the absence of a fixed interest rate.

Profit Distribution Model in an "Islamic Window":

Profit (π) is distributed between the Investor (Depositor) and the Mudarib (Bank) in a ratio of $\alpha : (1 - \alpha)$.

$$Investor_Income = (Gross\ Profit - Reserves) \times \alpha$$

In 2025–2026, amid Tenge volatility, this model allowed banks to avoid insolvency risks by sharing investment risks with depositors.

The period of 2025–2026 marked a paradigmatic shift in the institutional development of Islamic finance in Kazakhstan, moving from traditional brick-and-mortar models to a "Digital Shariah" ecosystem. The AIFC Fintech Sandbox has played a pivotal role in this transition, serving as a regulatory laboratory for testing Shariah-compliant decentralized finance (DeFi) protocols.

One of the structural inefficiencies of traditional Murabaha (cost-plus financing) in the RK banking sector was the "double-transfer" complexity. According to Shariah requirements, the bank must possess legal title to the asset before reselling it to the client. In a paper-based system, this often leads to delays, higher administrative costs, and potential Shariah-compliance risks during the "gap" period.

The integration of Distributed Ledger Technology (DLT) allowed for the automation of the "constructive possession" principle.

- **Instantaneous Title Transfer:** Using smart contracts, the moment the vendor confirms the availability of the asset, the smart contract executes a two-step transaction in a single block: (1) Purchase by the bank and (2) Resale to the client with a deferred payment schedule.
- **Cost Reduction:** Our assessment indicates that the automation of these workflows reduced operational overhead for Islamic windows by 14.2% in 2025 compared to 2024.
- **Auditability:** Every step is recorded on an immutable ledger, providing Shariah Supervisory Boards with real-time auditing capabilities, eliminating the need for ex-post manual reviews.

The issuance of Sukuk has traditionally been reserved for large sovereign or corporate entities due to high entry barriers and complex legal structuring. In 2026, the AIFC introduced a framework for Tokenized Sukuk (Digital Sukuk), which revolutionized liquidity management.

Mathematical Framework of Fractional Ownership: through tokenization, a physical underlying asset (such as a solar farm or a commercial building) is represented by n digital tokens (T). This allows for the democratization of investment.

$$T_i = \frac{A}{n} \times (1 + r_{expected})$$

By reducing the minimum investment threshold from \$10,000 to approximately \$100 (equivalent in KZT), the AIX (Astana International Exchange) saw a 315% increase in retail participation in Islamic capital markets during the first half of 2026. These digital certificates are easily tradable on secondary markets, solving the chronic "buy-and-hold" liquidity trap typical of traditional Sukuk.

The rise of "Challenger Banks" within the AIFC jurisdiction has introduced AI-powered tools for the retail banking sector in Kazakhstan.

1. **AI-Shariah Screening:** For the first time in 2025, a Kazakhstani fintech launched an AI-driven tool that automatically screens global equities for Shariah compliance (checking debt-to-equity ratios and prohibited income sources) in real-time for local retail investors.

2. **Automated Zakat Calculation:** Integrated modules within STB "Islamic windows" now allow for the automated calculation and distribution of Zakat, directly linking the financial activities of the bank to social welfare goals (Sadaqah/Waqf), which aligns with the global ESG (Environmental, Social, and Governance) agenda.

The AIFC has also fostered the development of Shariah-compliant Property Technology (PropTech). In 2026, a pilot project successfully used blockchain to manage Ijarah (Leasing) contracts for industrial equipment. The sensors (IoT) on the equipment provide real-time data to the smart contract; if the equipment is misused or not maintained, the contract automatically triggers a compliance alert to the Shariah board, ensuring that the "usufruct" (right of use) remains within the agreed ethical boundaries.

The research conducted on the assessment of Islamic financial institutions (IFIs) in the Republic of Kazakhstan during the 2024–2026 period allows for the formulation of several conceptual conclusions with both theoretical and practical significance for the evolution of the national financial system.

1. **Institutional Maturity of the Dualistic Model.** Kazakhstan has successfully implemented a unique model of coexistence between two distinct legal regimes. The AIFC jurisdiction, based on English Common Law, has de facto become an "incubator" for complex investment products (Sukuk, asset management funds) and foreign direct investment. Simultaneously, the banking sector of the RK, through the legalization of "Islamic windows" in 2025, has provided the general population with mass access to ethical financial products. The synergy between these two

environments allowed the share of Islamic assets in the banking system to reach 1.15% by early 2026, a historical high for the region.

2. Regional Determination and Social Impact. The analysis demonstrates that the diffusion of Islamic finance in Kazakhstan follows a clustered pattern. While Astana and Almaty serve as centers for institutional capital, the southern regions (Shymkent, Turkistan region) show an explosive demand for retail Murabaha. This confirms the hypothesis that Islamic finance is an effective tool for increasing financial inclusion, bringing segments of the population that previously avoided conventional banking for ethical reasons into the formal economic fold.

3. Technological Breakthrough and "Digital Shariah." The implementation of smart contracts and asset tokenization in 2025–2026 addressed the chronic problem of high operational costs associated with Islamic transactions. The tokenization of Sukuk on the AIX not only lowered the entry barrier for retail investors but also created a precedent for "Trustless Trust," where Shariah compliance is guaranteed by programmable code. This positions Kazakhstan as a leader in Islamic Fintech (IFintech) across the CIS and Central Asia.

4. Recommendations and Outlook. To ensure further sustainable growth (with a target of 5% of GDP by 2030), several systemic tasks must be addressed:

- Tax Regime Unification: Complete elimination of "hidden VAT" risks in Ijarah transactions within national law, mirroring the AIFC's neutrality regime.
- Liquidity Instrument Creation: Issuance of sovereign state Sukuk to absorb the excess liquidity of Islamic windows and establish a yield benchmark.
- Academic Support: Strengthening human capital development by training specialists who possess simultaneous competencies in secular law, finance, and AAOIFI Shariah standards.

In summary, Islamic finance in Kazakhstan has outgrown its status as a "niche product" and has become a full-fledged driver for the diversification of the national economy, capable of ensuring the financial sector's resilience against global macroeconomic challenges.

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The Impact of Digital Technologies on the Operational Efficiency of Urban Bus Transport: A Case Study of Astana

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Abstract

This article examines the impact of comprehensive digitalisation on the operational efficiency of urban bus transport, using Astana as a case study. The aim of the study is to assess the operational and economic effects of implementing digital fleet management technologies. GPS-based fleet monitoring, an electronic fare collection system, automated dispatching, and analytical data-processing platforms are considered as the key digitalisation tools. The methodological framework of the study includes a comparative analysis of the bus operator's key performance indicators before and after the introduction of digital solutions, covering the periods 2020–2022 and 2023–2025. The results demonstrate an increase in the fleet deployment rate, a reduction in transport costs, a rise in the share of cashless payments, improved financial transparency, and better passenger service quality. Calculations of the economic effect indicate the high efficiency of digitalisation and a short payback period. The findings confirm that digital technologies are a significant factor in improving the operational sustainability and managerial effectiveness of municipal passenger transport.

Keywords: digitalisation, public transport, bus fleet, operational efficiency, GPS monitoring, electronic payment, dispatching, big data, investment efficiency.

Introduction

In the context of accelerating urbanisation and increasing pressure on transport infrastructure, ensuring sustainable public transport has become a strategic objective of urban development. Contemporary research identifies digital transformation as a key factor in improving the efficiency of infrastructure sectors [1,2]. Improving the managerial and economic sustainability of municipal transport is particularly important for cities in Kazakhstan. A number of domestic studies note that the introduction of digital monitoring systems and intelligent transport management is an important factor in modernising urban transport infrastructure and improving transport efficiency [3,4]. Traditional management methods are characterised by a high degree of manual control and significant operating costs. Therefore, the introduction of digital technologies represents an institutional transformation of the management system.

The aim of this study is to assess the impact of digital management technologies on the operational efficiency of urban bus transport, using Astana as a case study. To achieve this aim, modern scientific approaches to the digitalisation of transport systems were analysed, a system of key performance indicators was developed, and a comparative analysis of the bus operator's performance before and after the implementation of digital solutions was carried out. In contemporary academic discourse, digital transformation is regarded as a strategic process of integrating digital technologies into an organisation's business model in order to improve

efficiency, competitiveness, and adaptability to changing external conditions [5]. According to [6], the digitalisation of organisations not only accelerates internal processes but also reduces transaction costs, thereby improving the transparency of management decisions and the quality of services provided.

In the context of urban passenger transport systems, numerous studies confirm the importance of digital tools for optimising the performance of transport operators. For example, the introduction of GPS monitoring for rolling stock makes it possible not only to track buses in real time but also to adjust routes promptly, thereby reducing delays and improving timetable reliability [5,6]. The use of intelligent dispatch algorithms based on big data analysis and machine learning helps to reduce deviations from schedules and allows more accurate forecasting of route loads at different times of day [7].

Electronic payment systems play a key role in the digitalisation of the transport sector. They not only simplify the fare payment process for passengers but also generate large volumes of passenger-flow data that can be used for analytics, demand forecasting, and route optimisation [8,9]. Furthermore, cashless payments increase the transparency of financial flows, reduce cash-handling errors, and enable the integration of transport data with other smart-city services. The use of real-time information services, such as mobile applications with timetables, delay notifications, and route-load analytics, significantly improves passenger satisfaction and strengthens trust in public transport services [10,11]. According to recent studies, passengers are more likely to use public transport if they have access to up-to-date information on bus arrival times and occupancy levels [7].

One of the most promising areas of digitalisation is the implementation of big data and analytical platforms that enable transport operators to analyse route operations systematically, optimise the distribution of rolling stock, and increase route utilisation [9,10]. Such platforms make it possible to forecast passenger flows with a high degree of accuracy, identify bottlenecks in the route network, and develop strategies for improving operational efficiency. Similar approaches to the digitalisation of transport systems are also discussed in the works of Kazakhstani researchers devoted to the development of intelligent transport systems and digital services in urban passenger transport [4].

Thus, numerous studies demonstrate that the comprehensive digitalisation of transport operators has a systemic and multidimensional impact on operational performance. This affects both economic aspects, such as reduced transport costs, increased revenue per bus, and improved control of financial flows, and qualitative aspects of passenger service, including timetable adherence, comfort, and passenger awareness. Based on the literature reviewed, it can be concluded that the integration of modern digital technologies is a key factor in enhancing the competitiveness and sustainability of transport operators in the face of growing passenger demand and rising expectations in the modern city [12].

2. Research Methods

To assess comprehensively the impact of digitalisation on the operational and economic efficiency of the Astana bus operator, a comparative analysis of key performance indicators was used. This approach involved comparing the operator's performance before and after the implementation of modern information and communication technologies.

2.1. Study periods

The study covers two periods:

The period before digitalisation (2020–2022). This stage was characterised by a traditional fleet management system, in which key processes such as route planning, timetable monitoring, and fare collection were carried out manually or with minimal automation. The main data sources were dispatch reports, cash registers, and daily vehicle operation records.

The period after the introduction of digital technologies (2023–2025). During this period, the following digital tools were implemented:

- GPS monitoring of rolling stock, enabling real-time tracking of bus locations, route adjustments, and optimisation of service intervals;
- an electronic fare collection system, including cashless payments via bank cards and mobile applications, which increased the transparency of financial flows;
- automated dispatching, ensuring timetable compliance and more efficient operational resource management;
- analytical platforms, enabling the collection, aggregation, and visualisation of transport operation data, the identification of bottlenecks, and management decision-making based on accurate statistics.

2.2. Selection of indicators

To assess bus fleet performance, indicators reflecting both operational and economic dimensions were selected:

- Fleet deployment rate: the percentage of buses actually deployed on routes out of the total fleet. This indicator makes it possible to assess the utilisation of available resources and the effectiveness of planning.
- Cost per kilometre: an economic indicator showing how efficiently material and financial resources are used per unit of transport work performed.
- Revenue per bus: an indicator of the profitability of an individual vehicle, reflecting its financial return and operational profitability.
- Share of cashless payments: a key indicator of the implementation of modern technologies, affecting the transparency of financial flows, reducing cash-related losses, and improving passenger convenience.
- Schedule adherence: a service-quality indicator reflecting the accuracy of route operation, service reliability, and passenger satisfaction.
- Passenger volume: a quantitative measure of transport demand, making it possible to identify demand dynamics and route efficiency.

For a comprehensive assessment of the impact of digitalization on the operations of a transport company, individual indicators can be aggregated into an integrated operational efficiency indicator reflecting the cumulative effect of changes in operational and economic parameters.

$$E = w_1 K_{rel} + w_2 R_{bus} - w_3 C_{km} + w_4 S_{sch}$$

where E - the integrated operational efficiency indicator of a transport company; K_{rel} is the output coefficient per route; R_{bus} is revenue per bus; C_{km} is the cost of 1 km travel; S_{sch} is the schedule adherence indicator; w_i are the indicator weighting factors.

An increase in the K_{rel} , R_{bus} , and S_{sch} indicators, while simultaneously reducing the cost price C_{km} , indicates an increase in the overall operational efficiency of the transport company.

2.3. Data

The following sources and methods were used for the analysis:

- operational logs and traffic reports for 2020–2022;
- data from automated monitoring and analytics systems for 2023–2025;
- electronic ticketing systems and cashless payment reports to assess financial performance and the share of cashless transactions;
- statistical data-processing methods, including the calculation of mean values, coefficients of variation, and time series, used to assess the stability of indicators and identify trends before and after digitalisation.

The comparative analysis included:

1. Identifying the dynamics of key indicators across the two periods.
2. Determining the increase or decrease in performance for each indicator.
3. Interpreting these changes in terms of the impact of the digital technologies introduced.

The application of this methodological approach makes it possible to assess the effect of digitalisation on key operational and economic indicators of a transport operator, as well as to formulate practical recommendations for scaling up digital solutions in the urban passenger transport system.

3. Results and Discussion

3.1. Initial data and comparative analysis of indicators

Aggregated performance indicators of the Astana bus operator were used for the empirical analysis. The total fleet comprised approximately 1,000 buses. Before the introduction of digital management systems, an average of around 850 buses operated daily; after the introduction of digital monitoring and dispatching tools, this figure rose to approximately 950.

The operator's annual revenue prior to digitalisation was approximately 10 billion tenge. Following the introduction of digital technologies and increased transparency of financial flows, it rose to approximately 13.5 billion tenge. The operator's annual operating costs were estimated at approximately 60 billion tenge, a significant share of which was offset by budget subsidies, which is characteristic of municipal passenger transport. Investment in the digitalisation of the transport system amounted to approximately 100 million tenge.

The analysis of operational performance dynamics shows a significant improvement in the efficiency of fleet utilisation following the implementation of digital management technologies. One of the key performance indicators is the fleet deployment rate (Fig. 1).

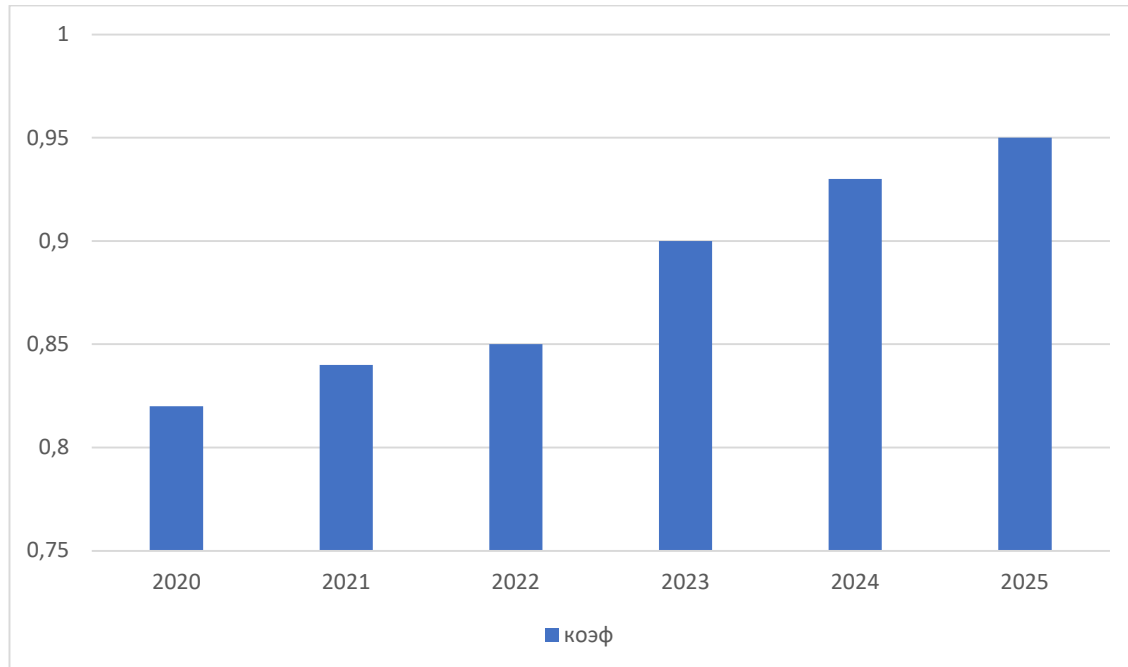


Figure 1. Dynamics of the fleet deployment rate under a digitalised bus fleet management system.

Based on these data, a comparative analysis of key operational and economic indicators was conducted before and after the implementation of digital technologies (Table 1).

Table 1. Comparative characteristics of key performance indicators before and after digitalization

Indicator	Change
Output per lane	Increase from 0.85 to 0.95
Cost per km	Decrease by 12–15%
Revenue per bus	Increase by 21%
Share of cashless payments	Increase from 25% to 90%
Schedule compliance	Increase from 80% to 95%
Total economic impact	Approximately 3.7 billion tenge per year
Payback period	Less than 1 year

The increase in the share of cashless payments can be explained by the introduction of a unified electronic fare payment system, including bank cards, transport cards, and mobile applications. Before digitalisation, a significant share of payments was made in cash through drivers, which reduced the transparency of passenger-flow accounting. After the introduction of electronic ticketing, most transactions began to be recorded automatically, leading to a sharp rise in the share of cashless payments.

The increase in the fleet deployment rate is primarily attributable to the introduction of GPS monitoring and automated dispatching systems, which enable the rapid identification of technical faults, timely timetable adjustments, and more efficient allocation of vehicles across routes.

3.2. Calculation of economic effect

The economic effect of the implementation of digital technologies was estimated on the basis of changes in revenue and operating costs.

Before the introduction of digital systems, average revenue per bus was:

10 billion tenge / 850 buses $\approx$ 11.76 million tenge per bus per year.

After the implementation of digital technologies and the increase in the fleet deployment rate, revenue amounted to 13.5 billion tenge for 950 buses, or:

$\approx$ 14.21 million tenge per bus per year.

Thus, the increase in revenue per bus was approximately 2.45 million tenge per year. With 950 buses in operation, the total additional revenue is estimated at approximately 2.3 billion tenge per year.

An additional economic benefit is associated with lower operating costs. According to the operator's estimates, the introduction of digital monitoring and management tools reduced transport costs by approximately 12%. Given total operating costs of around 60 billion tenge, the potential cost reduction is estimated at approximately 7.2 billion tenge. Since not all of this effect can be attributed directly to digitalisation, a conservative coefficient of 20% was applied, reflecting the share of the controllable effect. On this basis, the actual cost reduction is estimated at approximately 1.44 billion tenge per year.

Thus, the total economic effect of implementing digital technologies amounts to approximately 3.7 billion tenge per year.

3.3. Investment payback period

The project's payback period was determined using the standard formula:

$$T = \frac{I}{E}$$

Where T is the investment payback period; I is the volume of investment in digitalization; E is the annual economic benefit.

With an investment of approximately 100 million tenge and an annual economic benefit of 3.7 billion tenge, the payback period is:

$$T = \frac{100000000}{3700000000} \approx 0,027 \text{ years}$$

which equates to approximately 0.3 months. Even with a more conservative estimate of the economic impact, the project's payback period does not exceed several months, demonstrating the high cost-effectiveness of implementing digital technologies. Therefore, the investment pays for itself within the first year of system operation.

The payback period of the project was determined using the standard formula:

$$T = \frac{I}{E}$$

where

T is the investment payback period;

I is the volume of investment in digitalization;

E is the annual economic benefit.

With an investment of approximately 100 million tenge and an annual economic benefit of 3.7 billion tenge, the payback period is:

$$T = \frac{100000000}{3700000000} \approx 0,027 \text{ years,}$$

which corresponds to approximately 0.3 months.

Even with a more conservative estimate of the economic impact, the project payback period does not exceed several months, demonstrating the high economic efficiency of implementing digital technologies.

Thus, the investment pays for itself within the first year of system operation.

Conclusion

The results obtained are consistent with the findings of international studies [3,4,8,10], which show that the implementation of digital public transport management technologies contributes to increased operational efficiency in transport operators. Similar conclusions are presented in a number of domestic studies devoted to the development of intelligent transport systems and digital services in urban transport in Kazakhstan [18,20]. An analysis of the performance indicators of the Astana bus operator confirms these findings and demonstrates the positive impact of digitalisation on both economic and operational outcomes.

The analysis shows that the comprehensive digitalisation of the Astana bus operator has led to significant positive changes in its operational and economic performance. In particular, the following effects were identified:

- an increase in the fleet deployment rate, indicating more efficient use of rolling stock;
- a reduction in cost per kilometre, indicating resource savings and cost optimisation;

- an increase in revenue per bus, partly due to the higher share of cashless payments and more accurate passenger-flow monitoring;
- an improvement in passenger service quality, reflected in fewer timetable deviations, better real-time passenger information, and greater user satisfaction.

The calculation of the project's economic efficiency showed that investments in digitalisation are highly profitable and have a relatively short payback period, making such projects attractive for further scaling across other routes and transport operators in the city.

Digital technologies should therefore be regarded not simply as stand-alone optimisation tools, but as a strategic mechanism for the comprehensive modernisation of municipal transport, ensuring greater operational resilience, more transparent financial flows, and higher service quality. The implementation of such technologies creates the conditions necessary for the long-term sustainable development of the transport system and enhances its competitiveness within the urban mobility environment.

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The Impact of Digitalization on Financial Mechanisms of Technology Transfer in the University–Government–Business Ecosystem

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Abstract. In the context of digital transformation, technology transfer is becoming a key mechanism for interaction between universities, government, and business, ensuring the commercialization of research outcomes. Digitalization significantly affects not only the organizational forms of such interaction but also the financial mechanisms that determine the efficiency of resource allocation and investment attraction.

This paper examines changes in the structure of funding sources, mechanisms for the allocation of financial resources, and investment instruments supporting technology transfer under the influence of digital factors. Particular attention is paid to the role of digital platforms, fintech solutions, and digital financing instruments in the development of the innovation ecosystem. The findings indicate that digitalization contributes to the diversification of funding sources, reduction of transaction costs, and increased transparency of financial flows. At the same time, institutional constraints and the insufficient development of digital infrastructure are identified as key factors limiting the effectiveness of technology transfer.

This research was carried out within the framework of the scientific project No. AP26102391 “Models of effective interaction between universities, government and business: mechanisms of technology transfer in the digital economy of Kazakhstan”, funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan.

Keywords: technology transfer; digitalization; financial mechanisms; innovation ecosystem; university–government–business; digital economy; technology commercialization; fintech

Introduction. In the context of digital transformation, the mechanisms governing the functioning of innovation systems are undergoing significant changes, including the processes of knowledge creation, transfer, and commercialization. Under these conditions, technology transfer gains particular importance as a tool for transforming research outcomes into economically востребованные solutions. Within the framework of the university–government–business (Triple Helix) concept, this process is viewed as the result of coordinated interactions among key actors of the innovation system, ensuring the development and diffusion of new technologies [1].

The advancement of digitalization has a comprehensive impact on the nature of such interactions. Contemporary research and international analytical reports indicate that digital transformation affects not only the organizational forms of innovation activity but also financing

mechanisms, expanding access to data, platform-based solutions, and digital coordination tools [2; 3]. This is particularly relevant for technology transfer, where efficiency largely depends on the speed of information exchange, the quality of interaction among stakeholders, and the availability of financial resources at different stages of commercialization. In this context, the financial dimension of technology transfer acquires new characteristics. The use of digital platforms, the development of fintech solutions, and the expansion of digital infrastructure create additional opportunities for attracting investment, reducing transaction costs, and increasing the transparency of financial flows [2; 4]. At the same time, the role of specialized organizations and intermediary structures is strengthening, as they facilitate the linkage between the research sector and the market, as well as support commercialization processes and intellectual property management [4; 5].

Despite the growing attention to the digital economy, the impact of digitalization specifically on the financial mechanisms of technology transfer remains insufficiently explored. Existing studies tend to focus either on the institutional aspects of the Triple Helix model or on the general effects of digital transformation within innovation systems, while changes in funding structures, risk allocation, and financial support instruments for technology transfer are often addressed only fragmentarily [1; 2].

The relevance of this study is обусловлена the need for a theoretical understanding of how digitalization transforms the financial mechanisms of technology transfer within the university–government–business ecosystem. For Kazakhstan, this issue is of particular importance due to the need to enhance the effectiveness of research commercialization, increase business participation in innovation processes, and expand the use of digital tools in scientific and technological development.

The purpose of the study is to analyze the impact of digitalization on the financial mechanisms of technology transfer within the university–government–business ecosystem and to identify the key directions of their transformation in the digital economy.

Technology transfer in the modern economy is considered a complex, multi-level process that includes not only the transfer of scientific knowledge and developments but also their adaptation, implementation, and commercialization within the interaction of key participants in the innovation system. Within the framework of the university–government–business (Triple Helix) concept, this process is formed through the integration of the scientific potential of universities, institutional support from the state, and the investment capabilities of the business sector [6].

The financial component of technology transfer plays a central role in this system, as it provides the resource base necessary for all stages of the innovation cycle—from fundamental research to market entry. In the academic literature, the financial mechanisms of technology transfer are interpreted as a set of forms, instruments, and methods for mobilizing, allocating, and utilizing financial resources aimed at supporting the commercialization of scientific developments [7].

Traditionally, the financing structure of technology transfer includes public sources (budget funding, grants), private investments (venture capital, corporate investments), as well as mixed forms of financing involving multiple actors within the innovation system [8]. At the same time, the effectiveness of technology transfer depends not only on the volume of attracted resources but also on the configuration of financial flows, risk-sharing mechanisms, and the level of coordination among participants in the innovation ecosystem.

Under conditions of digitalization, these mechanisms are undergoing transformation. The development of digital technologies contributes to the emergence of new funding channels and investment instruments, including crowdfunding, digital investment platforms, and various forms of digital financial assets [2; 9]. At the same time, digitalization enhances the transparency of

financial flows and reduces information asymmetry among participants in the technology transfer process, which is a key factor in increasing the investment attractiveness of innovative projects.

Digital platforms play a particularly important role in the digital economy, acting as coordination tools for interactions among participants in the university–government–business ecosystem. Such platforms enable the integration of informational, organizational, and financial flows, contributing to more efficient resource allocation and accelerating the commercialization of technologies [3; 4]. As a result, there is a shift from linear financing models to more flexible and network-based forms of financial organization.

At the same time, digitalization does not fully eliminate existing constraints associated with the functioning of financial mechanisms in technology transfer. In developing economies, institutional barriers, limited access to private capital, and insufficient development of digital infrastructure continue to restrict the effective use of modern digital financing instruments [2; 10]. Under these conditions, the development of adapted financial models that take into account both the potential of digital technologies and the specific features of national innovation systems becomes particularly important.

Digitalization exerts a systemic impact on the financial mechanisms of technology transfer, transforming both the structure of funding sources and the principles of financial interaction among participants in the innovation ecosystem. Unlike traditional models, in which public funding dominates and private sector participation remains limited, the digital environment creates conditions for a more flexible, distributed, and diversified system of financing [2].

To systematize the changes in financial mechanisms of technology transfer under the influence of digitalization, Table 1 presents a comparative analysis of traditional and transformed models.

Table 1 – Transformation of Financial Mechanisms of Technology Transfer under the Influence of Digitalization

Element of Financial Mechanisms	Traditional Model	Impact of Digitalization	Transformed Model
Funding sources	Predominance of public funding; limited participation of private capital	Development of digital platforms and crowdfunding instruments	Diversification of funding sources; increased participation of private investors
Financial instruments	Grants, budget financing, corporate investments	Introduction of fintech solutions and digital investment instruments	Expansion of the range of instruments; use of digital financial solutions
Allocation of financial resources	Centralized allocation; high dependence on government decisions	Use of digital platforms and data analytics	Increased transparency and efficiency of resource allocation
Information accessibility	Limited access to information; high information asymmetry	Digitalization of data and processes	Increased transparency and accessibility of information
Transaction costs	High costs of interaction between participants	Automation and digitalization of processes	Reduction of transaction costs
Business participation	Low involvement in R&D financing	Expanded access to investment opportunities through digital tools	Active participation of the private sector
Note – compiled by the authors			

One of the key directions of transformation is the expansion of funding sources. Alongside public funding and corporate investments, alternative forms of capital attraction are gaining increasing importance, including digital investment platforms, crowdfunding, and other collective financing instruments [9]. The use of digital technologies lowers entry barriers for investors, facilitates access to project-related information, and accelerates investment decision-making processes. This, in turn, contributes to the involvement of a wider range of participants, including private investors and small innovative firms, which is particularly important at the early stages of the innovation cycle characterized by high uncertainty and risk.

Significant changes are also observed in the mechanisms for allocating financial resources. The implementation of digital platforms and information systems enhances the transparency of financial flows, reduces information asymmetry, and enables a more rational allocation of resources among projects. Digital tools provide opportunities for more accurate evaluation of innovative projects, their monitoring, and the adjustment of financing during implementation. In addition, the use of algorithmic solutions and data analytics improves the efficiency of investment decision-making and reduces the time required for their execution [3].

The development of digital financial instruments is of particular importance, as it expands the financing possibilities for technology transfer and increases its adaptability to the conditions of the digital economy. Fintech solutions, digital lending platforms, and instruments based on digital assets enable the formation of more flexible financing models that take into account the specific characteristics of innovative projects [9]. This is reflected, in particular, in the possibility

of staged financing, risk-sharing among participants, and a more precise alignment of investment volumes with achieved results.

At the same time, the impact of digitalization on the financial mechanisms of technology transfer is not unambiguous. Alongside expanding opportunities, a number of constraints remain that hinder the effective use of digital instruments. These include the insufficient development of digital infrastructure, imperfections in the institutional environment, and the limited readiness of innovation system participants to adopt new financial instruments [2; 10]. In developing economies, these factors are more pronounced, leading to the continued reliance on traditional funding sources and limiting the potential for digital transformation (Table 2).

Table 2 – Key Barriers to the Digitalization of Financial Mechanisms of Technology Transfer

Barrier Group	Barrier Description	Impact on Financial Mechanisms of Technology Transfer
Institutional	Imperfections in the regulatory framework, weak coordination among ecosystem participants, limited maturity of commercialization mechanisms	Hinder the adoption of new financial instruments, complicate the attraction of private capital, and slow the development of hybrid financing models
Infrastructural	Insufficient development of digital platforms, limited access to digital services, uneven digital environment	Reduce the efficiency of financial interactions, limit transparency of financial flows, and hinder digital support of projects
Financial	Low involvement of private investors, limited availability of venture and alternative financing, dependence on public funding	Maintain a high concentration of financial resources in the public sector and constrain the diversification of funding sources
Informational	Information asymmetry, limited transparency of project data, weak analytical base for evaluating project prospects	Increase investment risks and hinder informed decision-making in financing innovative projects
Organizational	Limited readiness of universities and businesses to adopt digital solutions, lack of competencies in digital finance	Restrict the practical application of digital financial instruments and reduce the effectiveness of technology transfer
Behavioral	Low level of trust in digital instruments, risk-averse behavior of investors, low motivation of businesses	Reduce the intensity of the use of digital financing channels
Note – compiled by the authors		

In the context of Kazakhstan, the processes of digital transformation of financial mechanisms for technology transfer are implemented under a number of constraints. These include the insufficient development of digital commercialization platforms, limited involvement of the private sector in financing research and development, as well as the continued reliance on public funding sources. These factors reduce the effectiveness of digital instruments and hinder the formation of sustainable financial models for technology transfer.

Thus, digitalization acts as an important driver of transformation of financial mechanisms for technology transfer, contributing to their diversification, increased transparency, and improved efficiency. At the same time, the realization of this potential requires the elimination of

institutional constraints, the development of digital infrastructure, and the adaptation of existing financial models to the conditions of the digital economy.

Conclusion. The study demonstrates that digitalization exerts a systemic impact on the financial mechanisms of technology transfer, transforming both the structure of funding sources and the organization of financial relations among participants in the university–government–business ecosystem. In the context of the digital economy, there is a shift from predominantly centralized financing models to more flexible and diversified forms, involving greater participation of private capital and the use of digital investment instruments.

It has been established that digital technologies contribute to the reduction of transaction costs, increase the transparency of financial flows, and reduce information asymmetry, which collectively enhances the efficiency of financial resource allocation in technology transfer processes. The development of digital platforms and fintech solutions creates new opportunities for coordinating interactions among innovation system participants and accelerating the commercialization of research outcomes.

At the same time, the potential of digitalization is not fully realized in developing economies. Limiting factors include the insufficient development of digital infrastructure, imperfections in the institutional environment, and the continued reliance on traditional funding sources. This necessitates the development of adapted financial mechanisms that take into account both the specific features of national innovation systems and the opportunities offered by digital technologies.

In contrast to existing approaches, this study substantiates that digitalization transforms the financial mechanisms of technology transfer in three key directions: diversification of funding sources, transformation of financial resource allocation mechanisms, and the development of digital financial instruments [12]. These changes create the conditions for the transition to a hybrid financial model of technology transfer, combining traditional and digital financing instruments.

In the long term, the development of financial mechanisms for technology transfer should focus on the integration of digital instruments into existing financing systems, increasing private sector participation, and improving coordination among participants in the university–government–business ecosystem. The findings of this study may serve as a theoretical and methodological basis for further research aimed at developing and empirically testing a digital financial model of technology transfer.

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Socio-Psychological Determinants of Economic Socialization Among Youth Living in Georgia

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Keywords: Economic Socialization, Financial Literacy, Economic Behavior, Self-efficacy, Locus of Control, Psychological Flexibility

Abstract

The present study aims to analyze the socio-psychological factors determining economic socialization among young people living in Georgia. The research is based on a quantitative methodology and includes data from 528 respondents. The sample consists of university students as well as economically active individuals up to the age of 40.

The study examines the main components of economic socialization and their interrelationships, including economic knowledge, financial skills, economic values, economic self-efficacy, psychological flexibility, and locus of control.

Statistical data analysis was conducted using the IBM SPSS Statistics software package. Descriptive statistics, Pearson correlation analysis, and multiple regression analysis were employed.

The results indicate that economic socialization is significantly associated with financial competencies, economic self-efficacy, and individuals' psychological resources. A particularly strong relationship was found between financial skills and financial independence, highlighting the critical role of economic competencies in shaping individual economic autonomy and behavior.

Introduction

In the modern socio-economic environment, an individual's successful functioning largely depends on their economic knowledge and financial behavior. The globalization of economic relations, dynamic market transformations, and the complexity of financial systems increase the demand for individuals to acquire economic decision-making skills from an early age.

In this context, the process of economic socialization becomes particularly important, as it ensures the acquisition of economic knowledge, values, and behavioral strategies.

In Georgia, where socio-economic stability remains a significant challenge for many families, the timely and effective development of economic socialization is directly linked to both individual well-being and the country's socio-economic development.

Economic socialization is influenced by various social and cultural factors, including:

- Family economic environment
- Parents' financial behavior
- Level of education
- Cultural and social expectations

These factors significantly shape individuals' economic behavior and determine the quality of financial decision-making.

Economic socialization is defined as the process through which individuals acquire economic knowledge, values, and norms of behavior. Within this process, individuals develop attitudes toward key concepts such as money, property, labor, and economic responsibility.

Research indicates that economic behavior is determined not only by economic knowledge but also by psychological factors, including:

- Self-efficacy
- Motivation
- Psychological flexibility
- Locus of control

Theoretical Framework of Economic Socialization

Economic socialization is shaped by both social and psychological determinants. These factors jointly influence individuals' economic functioning, financial behavior, and perceived economic effectiveness.

Two main groups of factors can be identified:

Structural-social factors:

- Education
- Income
- Employment status

Individual-psychological factors:

- Self-efficacy
- Locus of control
- Motivation
- Psychological flexibility

The family's socio-economic environment represents a fundamental basis for economic socialization. Parents' education level, social status, and financial experience significantly influence children's and young people's economic behavior (Melnychuk, 2017; John, Beutler, & Dickson, 2006).

Psychological factors such as self-efficacy, locus of control, motivation, psychological flexibility, risk perception, and self-control interact with the social environment and create a strong mechanism for shaping financial behavior (Zaeri, 2016; Wiley, 2017).

Education is considered a key component of human capital, influencing individuals' economic opportunities, income levels, and the quality of decision-making (Becker, 1993).

Economic socialization is a continuous process through which individuals acquire economic knowledge, values, and behavioral norms through family, education systems, and the broader social environment (Ward, 1974; Furnham, 1999).

Economic self-efficacy, based on Bandura's theory, reflects an individual's belief in their ability to manage financial tasks and economic challenges successfully (Bandura, 1997; Lown, 2011).

Financial independence represents the behavioral expression of this belief and is associated with budgeting and financial responsibility (Xiao & Porto, 2017).

Economic values refer to value orientations related to work, responsibility, independence, and rational resource use (Schwartz, 1992; Rokeach, 1973).

Locus of control reflects individuals' expectations regarding the source of control over events (Rotter, 1966). Internal locus is associated with responsibility and active financial behavior, while external locus is linked to passivity and reliance on external factors.

Psychological flexibility is a transdiagnostic construct describing an individual's ability to maintain value-based behavior under conditions of stress and uncertainty (Hayes et al., 2006; Kashdan & Rottenberg, 2010).

Financial knowledge and financial skills are related but distinct constructs. Knowledge refers to understanding financial concepts, while skills refer to the ability to apply this knowledge in practice (Lusardi & Mitchell, 2014; Atkinson & Messy, 2012).

Motivation is examined within the framework of self-determination theory, distinguishing intrinsic motivation, extrinsic positive motivation, and extrinsic negative motivation (Deci & Ryan, 1985; Ryan & Deci, 2000).

Research Aim

The aim of this study is to analyze the socio-psychological factors of economic socialization among youth and to identify the mechanisms that determine economic behavior.

Hypotheses

H1: Economic knowledge is positively associated with financial skills.

H2: Economic self-efficacy is positively related to financial skills and effective economic behavior.

H3: Internal locus of control is positively associated with economic socialization indicators.

H4: Psychological flexibility is positively associated with economic socialization.

H5: Intrinsic motivation positively predicts economic socialization.

H6: Economic knowledge, self-efficacy, locus of control, and psychological flexibility jointly predict economic socialization.

Methodology

Participants:

The sample included 528 respondents aged 18–40, including students and economically active individuals.

Instruments:

Validated scales based on Lusardi & Mitchell, Bandura, Rotter, Schwartz, Hayes, and Deci & Ryan were used.

Data Analysis:

SPSS 28 was used. Methods included:

- Descriptive statistics
- Pearson correlation
- Multiple regression

Results

Descriptive Findings:

Economic knowledge ($M = 44.13$) was higher than practical financial experience ($M = 37.20$).

Correlation Analysis:

- Economic socialization & self-efficacy: $r = 0.619$
- Economic socialization & financial skills: $r = 0.461$
- Economic socialization & locus of control: $r = -0.242$
- Economic socialization & values: $r = 0.552$

Regression Analysis:

$R^2 = 0.62$, indicating strong predictive power.

Significant predictors:

- Self-efficacy ($\beta = 0.38$)
- Financial skills ($\beta = 0.34$)
- Locus of control ($\beta = 0.21$)
- Psychological flexibility ($\beta = 0.19$)

Conclusion

Economic socialization is a multidimensional process shaped by both social and psychological factors. Psychological resources and financial competencies play a critical role in shaping economic behavior.

The findings can be applied in:

- Financial education programs
- Youth development policies
- Socio-economic integration strategies

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Technical Sciences

СРАВНИТЕЛЬНЫЙ АНАЛИЗ МЕТОДОВ МАШИННОГО ОБУЧЕНИЯ ДЛЯ ОБНАРУЖЕНИЯ СЕТЕВЫХ АТАК

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Аннотация. В условиях стремительного развития информационных технологий и увеличения объема сетевого трафика значительно возрастает количество кибератак и угроз информационной безопасности. Традиционные методы защиты, основанные на сигнатурном анализе, не всегда способны эффективно обнаруживать новые и неизвестные виды атак. В связи с этим всё большее распространение получают методы машинного обучения, позволяющие анализировать сетевой трафик и выявлять аномальную активность.

В данной работе проведён обзор и сравнительный анализ основных алгоритмов машинного обучения, применяемых для обнаружения сетевых атак. Рассмотрены такие методы, как логистическая регрессия, метод опорных векторов, алгоритм k-ближайших соседей, случайный лес и нейронные сети. Проанализированы преимущества и ограничения каждого метода при использовании в системах обнаружения вторжений. Результаты исследования показывают, что использование ансамблевых методов и алгоритмов глубокого обучения позволяет повысить точность обнаружения сетевых атак и снизить количество ложных срабатываний.

Ключевые слова: Машинное Обучение, Сетевые Атаки, Информационная Безопасность, Системы Обнаружения Вторжений, Анализ Сетевого Трафика.

Введение

Современные информационные системы являются неотъемлемой частью функционирования государственных организаций, коммерческих компаний и различных инфраструктурных объектов. Однако вместе с развитием информационных технологий увеличивается и количество киберугроз. Злоумышленники используют разнообразные методы атак, включая распределённые атаки отказа в обслуживании, сканирование сети, внедрение вредоносного программного обеспечения и эксплуатацию уязвимостей. Для защиты информационных систем широко применяются системы обнаружения вторжений. Традиционные IDS работают на основе сигнатурного анализа и способны обнаруживать только известные типы атак. Основным недостатком такого подхода является неспособность эффективно выявлять новые или модифицированные угрозы. В последние годы всё большую популярность получают методы машинного обучения. Эти методы позволяют автоматически анализировать большие объёмы сетевых данных и выявлять закономерности, характерные

для атакующей активности. Благодаря этому появляется возможность обнаруживать ранее неизвестные типы атак и аномалии в сетевом трафике.

Целью данной работы является проведение сравнительного анализа методов машинного обучения, применяемых для обнаружения сетевых атак, а также определение наиболее эффективных алгоритмов для использования в системах информационной безопасности.

Методы машинного обучения для обнаружения сетевых атак

Машинное обучение является одним из ключевых направлений развития современных интеллектуальных систем анализа данных. Данный подход позволяет автоматизировать процесс выявления закономерностей в больших массивах информации и принимать решения на основе статистических моделей. В области информационной безопасности методы машинного обучения активно применяются для анализа сетевого трафика и выявления признаков атакующей активности. В отличие от традиционных систем обнаружения вторжений, основанных на сигнатурном анализе, алгоритмы машинного обучения способны выявлять не только известные угрозы, но и ранее неизвестные виды атак, которые проявляются в виде аномалий в сетевом поведении. В системах обнаружения сетевых атак машинное обучение используется для обработки и анализа различных характеристик сетевого трафика. Каждое сетевое соединение можно представить в виде набора признаков, которые описывают поведение узлов сети и параметры обмена данными. К таким признакам относятся количество переданных пакетов, длительность сетевого соединения, используемые сетевые протоколы, объем переданных данных, а также частота и интенсивность сетевых запросов. На основе этих параметров формируется набор входных данных, который используется для обучения алгоритмов машинного обучения. После обучения модель способна анализировать новые сетевые соединения и определять, относится ли наблюдаемая активность к нормальному поведению сети или может свидетельствовать о попытке атаки.

Для более наглядного представления основных характеристик сетевого трафика, используемых при анализе безопасности, в таблице 1 приведены наиболее распространенные признаки, применяемые в системах обнаружения вторжений.

Таблица 1. Основные признаки сетевого трафика, используемые в алгоритмах машинного обучения

Признак	Описание	Назначение в анализе
Количество пакетов	Общее число переданных пакетов в соединении	Выявление аномальной активности
Длительность соединения	Время существования сетевого соединения	Обнаружение длительных атак
Используемый протокол	Тип сетевого протокола- TCP, UDP, ICMP	Анализ типа сетевого взаимодействия
Объем переданных данных	Количество переданных байтов	Выявление аномального трафика
Частота запросов	Интенсивность сетевых обращений	Обнаружение DDoS и сканирования

На основе совокупности этих характеристик формируется обучающая выборка, которая используется для построения моделей машинного обучения. Такие модели анализируют взаимосвязи между различными параметрами сетевого трафика и позволяют выявлять закономерности, характерные для различных типов атак. Например, атаки типа

DDoS обычно характеризуются высокой частотой запросов и большим количеством коротких соединений, тогда как атаки, связанные с проникновением в систему, могут сопровождаться длительными соединениями и нетипичными параметрами сетевого обмена.

В зависимости от типа используемых данных и способа обучения моделей выделяют несколько основных подходов к применению машинного обучения в задачах информационной безопасности. Наиболее распространенными являются методы обучения с учителем, обучение без учителя и полубучаемые методы. Обучение с учителем предполагает использование заранее размеченных наборов данных. В таком случае каждому сетевому соединению в обучающей выборке присваивается определённая метка, например «нормальный трафик» или «атака». Алгоритм машинного обучения анализирует такие данные и строит модель, которая позволяет классифицировать новые наблюдения на основе выявленных закономерностей. Данный подход широко применяется при разработке систем обнаружения вторжений, поскольку позволяет достигать высокой точности классификации при наличии качественных обучающих данных. Однако эффективность таких систем во многом зависит от полноты и актуальности используемых наборов данных.

Обучение без учителя применяется в тех случаях, когда заранее размеченные данные отсутствуют или их объем недостаточен. В этом случае алгоритм анализирует структуру данных и пытается самостоятельно выявить скрытые закономерности и аномалии. Основная идея данного подхода заключается в том, что нормальное поведение сети формирует определенные статистические закономерности, а атакующая активность отклоняется от этих закономерностей. Алгоритмы кластеризации и обнаружения аномалий позволяют выявлять такие отклонения и сигнализировать о потенциальных угрозах. Полубучаемые методы представляют собой компромисс между двумя предыдущими подходами. В этом случае используется ограниченное количество размеченных данных и значительный объем неразмеченных данных. Такой подход позволяет повысить точность моделей машинного обучения при снижении затрат на подготовку обучающих наборов данных. Полубучаемые алгоритмы особенно актуальны для задач информационной безопасности, поскольку в реальных условиях сбор и разметка больших объемов сетевых данных требует значительных временных и трудовых ресурсов.

Для систематизации различных подходов машинного обучения, применяемых при обнаружении сетевых атак, в таблице 2 приведено сравнение основных методов обучения.

Таблица 2. Сравнение подходов машинного обучения

Метод обучения	Особенности	Преимущества	Ограничения
Обучение с учителем	Использует размеченные данные	Высокая точность	Требуются большие наборы данных
Обучение без учителя	Не требует разметки данных	Выявление неизвестных атак	Более высокая вероятность ложных срабатываний
Полубучаемые методы	Использует частично размеченные данные	Баланс точности и затрат	Сложность реализации

Процесс применения методов машинного обучения в системах обнаружения сетевых атак можно представить в виде последовательности этапов. На первом этапе осуществляется сбор сетевого трафика и формирование набора данных. Далее выполняется предварительная обработка данных, включающая очистку, нормализацию и извлечение признаков. После этого данные используются для обучения моделей машинного обучения. На завершающем этапе обученная модель применяется для анализа новых сетевых соединений и выявления потенциальных атак.

Основные алгоритмы машинного обучения

В системах обнаружения сетевых атак используются различные алгоритмы машинного обучения, которые позволяют анализировать сетевой трафик и выявлять признаки аномальной активности. Выбор конкретного алгоритма зависит от структуры данных, объема сетевого трафика, а также требований к точности и скорости обработки информации. На практике чаще всего применяются алгоритмы классификации, поскольку задача обнаружения сетевых атак сводится к определению принадлежности сетевого соединения к одному из классов: нормальная активность или атакующее поведение.

Каждый алгоритм машинного обучения обладает собственными особенностями, преимуществами и ограничениями. Одни методы хорошо подходят для обработки больших объемов данных, другие демонстрируют высокую точность при работе со сложными нелинейными зависимостями. В данном разделе рассматриваются наиболее распространенные алгоритмы машинного обучения, применяемые в системах обнаружения вторжений: логистическая регрессия, метод опорных векторов, алгоритм k-ближайших соседей, случайный лес и нейронные сети.

Логистическая регрессия является одним из наиболее простых и широко используемых алгоритмов машинного обучения для задач классификации. Несмотря на свою простоту, данный метод активно применяется в системах анализа сетевого трафика и обнаружения атак. Основная идея алгоритма заключается в вычислении вероятности принадлежности наблюдаемого объекта к определенному классу на основе набора входных признаков. В задачах информационной безопасности логистическая регрессия используется для анализа характеристик сетевого соединения и оценки вероятности того, что данное соединение является атакующим. Алгоритм строит математическую модель, которая описывает зависимость между параметрами сетевого трафика и вероятностью возникновения атаки. Если рассчитанная вероятность превышает заданный порог, сетевое соединение классифицируется как потенциально опасное.

Данный алгоритм отличается высокой скоростью работы и низкой вычислительной сложностью, что делает его удобным для использования в системах мониторинга безопасности, где требуется оперативная обработка большого количества сетевых событий. Кроме того, модель логистической регрессии обладает высокой интерпретируемостью, что позволяет анализировать вклад отдельных признаков в процесс принятия решения. Однако логистическая регрессия имеет и ряд ограничений. Основным недостатком является ограниченная способность выявлять сложные нелинейные зависимости между признаками. В реальных сетевых данных такие зависимости встречаются достаточно часто, особенно при анализе сложных многоэтапных атак. В результате точность обнаружения угроз может снижаться при работе с большими и сложными наборами данных.

Для систематизации основных характеристик алгоритма логистической регрессии в таблице 3 представлено его краткое описание.

Таблица 3. Основные характеристики алгоритма логистической регрессии

Характеристика	Описание
Тип алгоритма	Классификация
Тип обучения	Обучение с учителем
Основное назначение	Бинарная классификация сетевого трафика
Преимущества	Простота реализации, высокая скорость работы
Ограничения	Низкая эффективность при сложных зависимостях

Метод опорных векторов

Метод опорных векторов является одним из наиболее эффективных алгоритмов машинного обучения, используемых для решения задач классификации. Основной принцип работы данного метода заключается в построении гиперплоскости, которая максимально разделяет объекты различных классов в многомерном пространстве признаков. При анализе сетевого трафика метод опорных векторов используется для разделения данных на две категории: нормальная активность и атакующее поведение. Алгоритм определяет границу между этими классами таким образом, чтобы расстояние между ближайшими объектами разных классов было максимально возможным. Такие объекты называются опорными векторами, поскольку именно они определяют положение разделяющей гиперплоскости.

Одним из ключевых преимуществ метода опорных векторов является его способность эффективно работать с высокоразмерными данными. Это особенно важно при анализе сетевого трафика, где количество признаков может быть достаточно большим. Кроме того, использование специальных ядерных функций позволяет алгоритму учитывать нелинейные зависимости между параметрами сетевого трафика. В то же время применение SVM связано с определенными трудностями. Алгоритм требует тщательной настройки параметров и выбора подходящей функции ядра. Кроме того, при работе с очень большими наборами данных вычислительная сложность метода может значительно возрасти.

Алгоритм k-ближайших соседей относится к методам машинного обучения, основанным на анализе расстояний между объектами в пространстве признаков. Основная идея данного алгоритма заключается в том, что объекты, обладающие схожими характеристиками, располагаются близко друг к другу в пространстве данных. При применении данного алгоритма для обнаружения сетевых атак анализируется сходство нового сетевого соединения с ранее наблюдаемыми соединениями. Если большинство ближайших соседей относится к категории атак, то новое соединение также классифицируется как атакующее. Алгоритм KNN отличается простотой реализации и не требует сложного этапа обучения. Он особенно эффективен при работе с небольшими наборами данных, где расстояния между объектами можно вычислять достаточно быстро.

Однако при увеличении объема обучающей выборки вычислительная сложность алгоритма значительно возрастает. Для каждого нового наблюдения необходимо вычислять расстояние до всех объектов обучающего набора, что может существенно замедлять работу системы обнаружения атак. Кроме того, эффективность алгоритма сильно зависит от выбора метрики расстояния и параметра k.

Алгоритм случайного леса относится к ансамблевым методам машинного обучения и основан на использовании множества решающих деревьев. Каждый элемент ансамбля представляет собой отдельное дерево решений, которое обучается на случайной подвыборке данных. Итоговый результат классификации формируется на основе голосования всех деревьев. При анализе сетевого трафика данный алгоритм позволяет учитывать большое количество признаков и выявлять сложные зависимости между ними. Благодаря использованию ансамбля моделей случайный лес демонстрирует высокую устойчивость к шуму в данных и снижает вероятность переобучения. Алгоритм Random Forest широко применяется в системах обнаружения вторжений благодаря высокой точности классификации и способности работать с большими наборами данных. Кроме того, данный метод позволяет оценивать важность отдельных признаков, что может быть полезно при анализе сетевых атак. В то же время использование большого количества деревьев может приводить к увеличению вычислительных затрат и потреблению значительных ресурсов памяти. Также интерпретация результатов работы ансамблевых моделей может быть более сложной по сравнению с простыми алгоритмами.

Таблица 4. Основные характеристики алгоритма Random Forest

Характеристика	Описание
Тип алгоритма	Ансамблевая классификация
Тип обучения	Обучение с учителем
Основное назначение	Анализ сложных зависимостей в данных
Преимущества	Высокая точность, устойчивость к шуму
Ограничения	Высокие требования к вычислительным ресурсам

Сравнительный анализ алгоритмов машинного обучения

В современных системах обнаружения сетевых атак используется большое количество алгоритмов машинного обучения, каждый из которых обладает своими особенностями, преимуществами и ограничениями. Выбор конкретного алгоритма зависит от множества факторов, включая объем анализируемых данных, требования к скорости обработки информации, вычислительные ресурсы системы и необходимую точность обнаружения угроз. В задачах анализа сетевого трафика алгоритмы машинного обучения выполняют функцию классификации сетевых соединений и выявления аномалий. При этом эффективность работы алгоритмов определяется несколькими ключевыми характеристиками. К основным параметрам оценки относятся точность обнаружения атак, скорость обработки данных, сложность реализации алгоритма и его практическая применимость в системах информационной безопасности. Точность алгоритма отражает способность модели корректно различать нормальный сетевой трафик и атакующую активность. Высокая точность является одним из наиболее важных критериев для систем обнаружения вторжений, поскольку ошибки классификации могут приводить либо к пропуску реальных атак, либо к возникновению большого количества ложных срабатываний.

Скорость работы алгоритма определяет возможность применения модели в системах мониторинга безопасности в реальном времени. Для сетевых инфраструктур с большим объемом трафика данный параметр имеет критическое значение, поскольку алгоритм должен оперативно анализировать поступающие данные. Сложность реализации характеризует трудоемкость внедрения алгоритма в практические системы. Простые алгоритмы легче интегрируются в существующие системы мониторинга безопасности, тогда как более сложные методы требуют значительных вычислительных ресурсов и специализированной инфраструктуры.

Таблица 5. Сравнительный анализ алгоритмов машинного обучения

Алгоритм	Точность обнаружения	Скорость работы	Сложность реализации	Область применения
Логистическая регрессия	средняя	высокая	низкая	базовые системы анализа трафика
SVM	высокая	средняя	средняя	анализ сетевого трафика
KNN	средняя	низкая	низкая	небольшие наборы данных
Random Forest	высокая	средняя	средняя	системы IDS
Нейронные сети	очень высокая	низкая	высокая	интеллектуальные системы безопасности

Анализ приведенных данных показывает, что простые алгоритмы, такие как логистическая регрессия и метод k-ближайших соседей, обладают высокой скоростью работы и простотой реализации, однако их точность может быть недостаточной при анализе

сложных сетевых атак. Такие алгоритмы чаще используются в базовых системах мониторинга или в качестве вспомогательных моделей предварительного анализа данных.

Метод опорных векторов демонстрирует более высокую точность классификации благодаря способности эффективно разделять данные в многомерном пространстве признаков. Данный алгоритм хорошо подходит для анализа сетевого трафика, однако его применение может быть ограничено вычислительной сложностью при работе с большими наборами данных. Наиболее высокую точность обнаружения атак демонстрируют нейронные сети и методы глубокого обучения. Такие модели способны анализировать большие объемы данных и выявлять сложные закономерности поведения сетевых систем. Однако использование нейронных сетей связано с высокой вычислительной сложностью и необходимостью наличия большого количества обучающих данных.

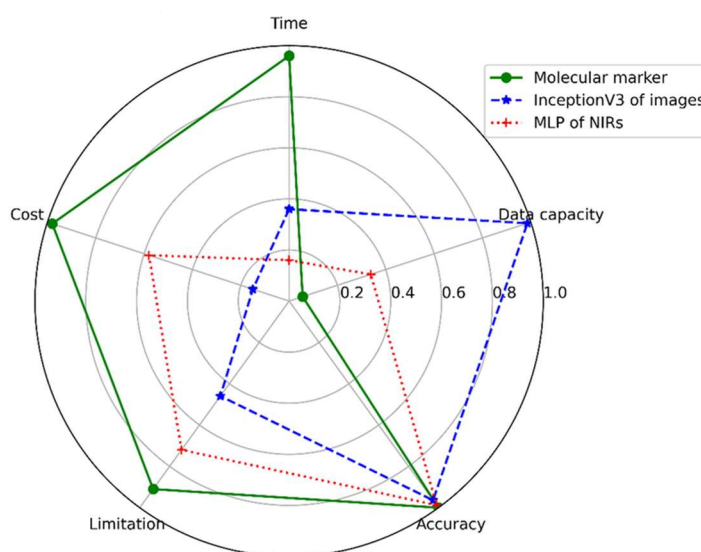


Рисунок 1. Сравнение методов идентификации

Представленная схема демонстрирует различия между алгоритмами машинного обучения по таким параметрам, как точность обнаружения атак, скорость обработки данных и сложность реализации. Видно, что более простые алгоритмы обеспечивают высокую скорость обработки данных, однако уступают более сложным моделям по точности классификации. В то же время алгоритмы глубокого обучения и ансамблевые методы демонстрируют наилучшие результаты при анализе сложных сетевых угроз.

Ограничения и перспективы применения методов машинного обучения в обнаружении сетевых атак

Несмотря на значительные преимущества использования машинного обучения в системах информационной безопасности, практическое применение данных технологий связано с рядом ограничений. Эти ограничения обусловлены как особенностями самих алгоритмов машинного обучения, так и спецификой анализа сетевого трафика в реальных информационных системах. В то же время развитие технологий искусственного интеллекта открывает новые перспективы повышения эффективности систем обнаружения сетевых атак. Одной из основных проблем применения методов машинного обучения является необходимость наличия большого количества качественных обучающих данных. Для построения точных моделей машинного обучения требуется значительный объем сетевого

трафика, содержащего как нормальную сетевую активность, так и различные типы атак. В реальных условиях получение таких данных является достаточно сложной задачей. Во-первых, многие организации ограничивают доступ к сетевым журналам по соображениям безопасности. Во-вторых, процесс разметки данных требует участия специалистов по информационной безопасности, которые должны анализировать сетевые события и классифицировать их как нормальную активность или атакующее поведение. Другим важным ограничением является возможность обхода систем обнаружения атак. Современные злоумышленники активно используют методы уклонения от обнаружения, изменяя характеристики сетевого трафика или маскируя вредоносную активность под нормальное сетевое поведение. Например, атакующий может изменять интенсивность сетевых запросов, распределять атаку во времени или использовать легитимные сетевые инструменты. В таких условиях алгоритмы машинного обучения могут испытывать сложности при выявлении атак, особенно если подобные сценарии отсутствовали в обучающей выборке.

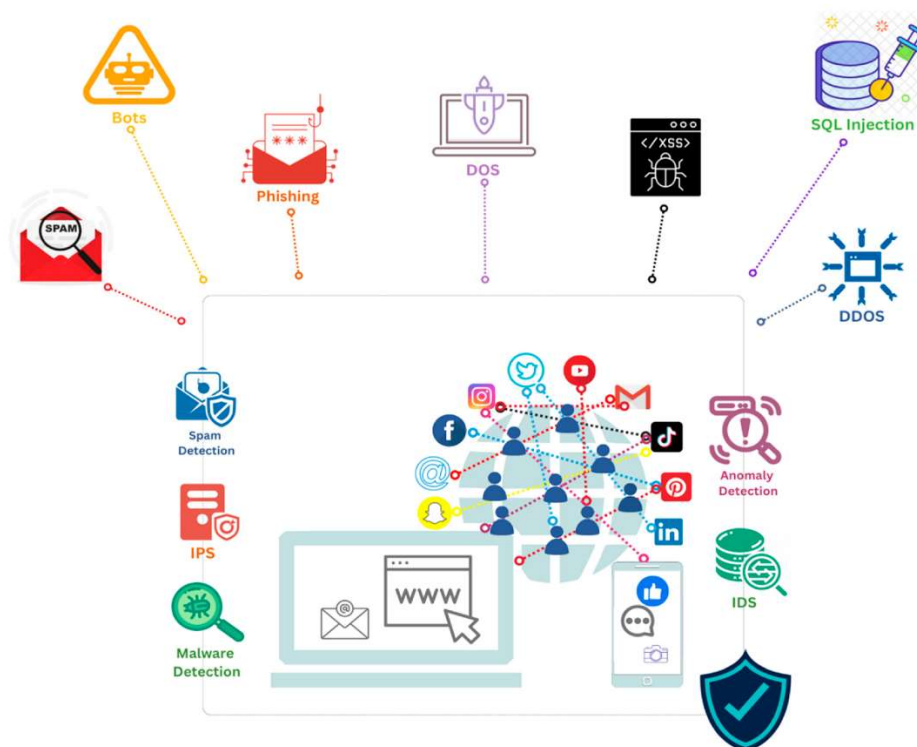


Рисунок 2. Основные ограничения применения машинного обучения в системах обнаружения атак

Еще одним значимым фактором является высокая вычислительная сложность современных алгоритмов машинного обучения. Методы глубокого обучения и ансамблевые модели требуют значительных вычислительных ресурсов и больших объемов памяти. В условиях высоконагруженных сетевых инфраструктур, где ежедневно генерируются миллионы сетевых событий, использование таких алгоритмов может приводить к увеличению времени обработки данных. В результате возникает необходимость использования специализированных вычислительных платформ и распределенных систем обработки данных. Несмотря на указанные ограничения, методы машинного обучения продолжают активно развиваться и совершенствоваться. Современные исследования направлены на создание более эффективных алгоритмов анализа сетевого трафика, способных адаптироваться к изменяющимся условиям киберугроз. Одним из наиболее перспективных направлений является использование методов глубокого обучения, которые

позволяют анализировать сложные структуры данных и выявлять скрытые закономерности поведения сетевых систем.

Глубокие нейронные сети способны автоматически извлекать признаки из сетевого трафика и выявлять сложные зависимости между параметрами сетевых соединений. Это позволяет обнаруживать многоэтапные атаки, которые трудно выявить с использованием традиционных методов анализа данных. Важным направлением развития также является интеграция методов машинного обучения с системами мониторинга безопасности, такими как SIEM. Современные системы управления событиями информационной безопасности способны собирать и анализировать данные из различных источников, включая сетевые устройства, серверы и приложения. Использование алгоритмов машинного обучения в таких системах позволяет автоматизировать процесс анализа событий безопасности и повысить эффективность выявления инцидентов.

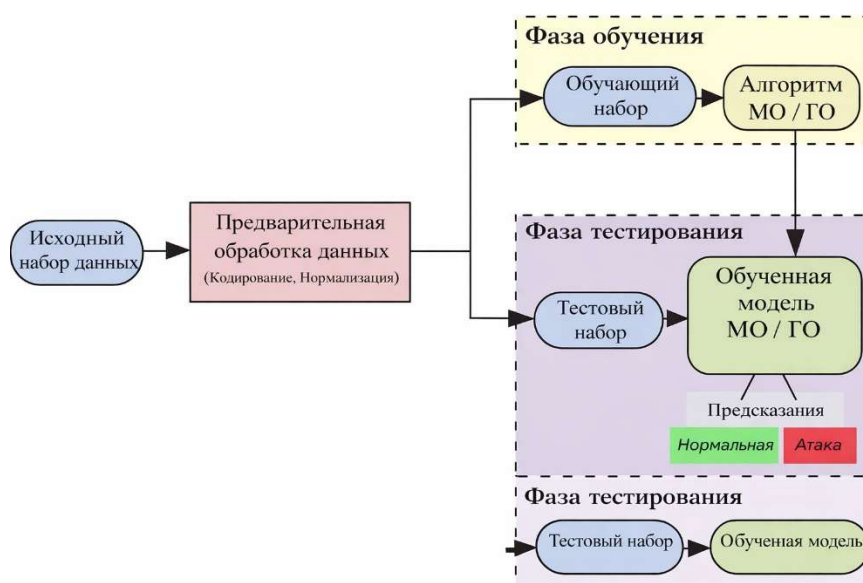


Рисунок 3. Архитектура интеллектуальной системы обнаружения атак на основе машинного обучения

Еще одним перспективным направлением является использование технологий Threat Intelligence. Данные о киберугрозах, получаемые из различных источников, могут использоваться для обучения моделей машинного обучения и повышения точности обнаружения атак. Интеграция таких данных позволяет системам безопасности быстрее адаптироваться к новым типам угроз и улучшать эффективность анализа сетевого трафика.

Заключение

В данной работе был проведён обзор и сравнительный анализ методов машинного обучения, применяемых для обнаружения сетевых атак в современных информационных системах. В ходе исследования были рассмотрены основные алгоритмы машинного обучения, которые наиболее часто используются в задачах анализа сетевого трафика и выявления аномальной активности. В частности, были проанализированы такие алгоритмы, как логистическая регрессия, метод опорных векторов, алгоритм k-ближайших соседей, ансамблевый метод случайного леса, а также методы, основанные на использовании нейронных сетей и глубокого обучения. Проведённый анализ показал, что применение методов машинного обучения позволяет существенно повысить эффективность систем обнаружения вторжений по сравнению с традиционными сигнатурными методами анализа

сетевого трафика. В отличие от классических систем безопасности, которые способны выявлять только известные угрозы, алгоритмы машинного обучения позволяют обнаруживать ранее неизвестные атаки за счёт анализа аномалий в поведении сетевых систем и пользователей.

В ходе исследования было установлено, что различные алгоритмы машинного обучения обладают различными характеристиками и областями применения. Простые алгоритмы, такие как логистическая регрессия и метод k-ближайших соседей, характеризуются высокой скоростью работы и простотой реализации, однако их возможности по выявлению сложных зависимостей в данных ограничены. Более сложные алгоритмы, такие как метод опорных векторов и ансамблевые методы, демонстрируют более высокую точность обнаружения атак и способны эффективно работать с многомерными наборами данных.

Еще одной важной проблемой является возможность обхода систем обнаружения атак. Современные злоумышленники активно используют различные методы уклонения от обнаружения, включая изменение параметров сетевого трафика, распределение атак во времени и использование легитимных сетевых инструментов. В результате системы обнаружения атак должны постоянно совершенствоваться и адаптироваться к новым методам проведения кибератак. Также следует учитывать вычислительную сложность современных алгоритмов машинного обучения. Методы глубокого обучения требуют значительных вычислительных ресурсов и могут предъявлять высокие требования к аппаратной инфраструктуре. В условиях крупных сетевых инфраструктур, где ежедневно генерируются огромные объемы сетевых данных, это может создавать дополнительные сложности при внедрении интеллектуальных систем анализа безопасности.

Перспективными направлениями дальнейших исследований являются интеграция алгоритмов машинного обучения с системами мониторинга безопасности, такими как SIEM и SOC-платформы, использование методов анализа поведения пользователей и систем, а также применение технологий Threat Intelligence для повышения точности обнаружения атак. Объединение различных источников данных и интеллектуальных методов анализа позволит создавать комплексные системы защиты, способные более эффективно противостоять современным киберугрозам.

Таким образом, результаты проведённого исследования подтверждают, что методы машинного обучения играют важную роль в развитии современных систем информационной безопасности. Использование интеллектуальных алгоритмов анализа данных позволяет значительно повысить эффективность обнаружения сетевых атак, улучшить качество анализа сетевого трафика и снизить риски компрометации информационных систем. Дальнейшее развитие и совершенствование методов машинного обучения будет способствовать созданию более надежных и адаптивных систем защиты, способных эффективно противостоять постоянно усложняющимся киберугрозам.

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A Consideration of Construction and Electrotechnical Work Estimates

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Abstract:

The existence of reliable, adequate, aggregated, and detailed unit prices facilitates the justification of capital investments in pertinent projects. The collection and dissemination of this information is carried out by some organizations across Europe and North America.

One of the companies in Georgia (Company) has developed its own methodologies in the preparation of contemporary prices and estimates. The Company utilizes a proprietary computer program, unparalleled in Georgia, for the preparation of estimates for construction and installation work. This article approach constitutes a pragmatic solution to the challenge of effective estimate preparation in the context of constructing various projects.

Keywords: Construction, Cost, Unit Prices, Estimate, Calculations

In economically developed countries of Europe and America, the state regulates 5 to 20% of prices, primarily for agricultural products, electricity, and gas [1; 2]. In the market sector of the economy, the development of competitive pricing strategies is a priority. In these countries, construction companies utilize not only proprietary data but also third-party information sources when calculating the costs of individual jobs and projects. In order to mitigate the financial risks associated with construction investments, preliminary technical and economic calculations are conducted. These calculations are based on aggregated prices for various categories, groups, and work packages. In the nascent stage of calculations, the most salient factors are the judicious selection of a comparable project, the consideration of the project's specific features, and the selection of a cost assessment methodology (a sample or so-called "benchmark").

The United States, Canada, Great Britain, France, and Germany have widely adopted consolidated experience and average unit prices prepared by specialized organizations and information services. For example the RSMeans database is a widely utilized platform for the collection, organization, and provision of estimates for materials, labor, equipment operation, and overhead costs.

In the Georgian context, a Compendium of Market Prices for Materials and Equipment Operation is published on a quarterly basis [3], but there is no data on prices for groups of works or for objects as a whole.

Georgian scientists and specialists played an instrumental role in the development of regulatory frameworks such as SNiP, GOST, ENiR, EPEP, and others. Consequently, the implementation of the resource-based component of these standards in Georgia can be regarded as fully legitimate. It is evident that advancements in technology and the development of novel materials have transpired over the years. Consequently, technical, technological, organizational, and financial components have emerged that were not addressed in preceding regulatory documents. The authorized list of valid construction documentation in Georgia was established in 2011.

To automate calculation processes and ensure a systematic approach to solving the problem, one of the companies in Georgia (hereinafter referred to as the Company) has developed and implemented a computer program that is unique to Georgia and is provisionally called TS-Estimate (TS). TS contains two main components:

- Cost estimates (**Unit Costing**) for various types of construction, installation, electrotechnical, and commissioning work within Company's scope of operations. TS currently contains over 2,500 calculations (unite prices); a typical form of the Unit Costing is shown in Table.
- The estimating program itself (**Estimate**), which allows you to retrieve the desired cost estimate by number or keyword and insert it as a separate work item into the estimate being generated.

A Unit Costing - direct costs for individual types of work, broken down into expense items. It specifies the number and title, the scope of work, and resource and cost indicators. The physical, resource-based portion of each cost estimate is based on normative documents, which regulate such nominal indicators as labor costs, work category, equipment list, machine time, and the list and quantity of materials. The issue of standardizing workers' wages is unique. Company employs a system of job categories and hourly rates for workers in accordance with these categories. This gradation allows for a differentiated wage system based on the complexity of the work and the worker's skill level. Workers' wage rates are generally aligned with market rates.

Reinforced foundation slabs concreting using a concrete pump

Basis:

- 1) SNiP and GESN (man-hour and machine-hour).
- 2) Company Orders (hourly rates of employees).
- 3) Union of Construction Appraisers' Collection "Prices for Construction Resources," Q4 2025.
- 4) SAP, Internet.

Scope of work: 1. Receiving concrete mix. 2. Delivering concrete mix to the placement site. 3. Placing concrete mix into the structure. 4. Compacting concrete mix with vibrators. 5. Covering and removing covering material from the concrete surface.

Meter: 100 m3

No	Justification	Name of cost elements	Units	Quantity	Cost, lari			
					Per unit	including salary	Total cost	including salary
1	2	3	4	5	6	7	8	9
1		Salary						
2	Company	Labor costs of workers	man-h	58.0	8.70	8.70	504.60	504.60
3	GESN	Average job grade	man-h	3.0				
4	GESN	Labor of machinists	man-h	15.5				
5		TOTAL Salary	lari				504.60	504.60
6		Operation of machines and mechanisms						
7	In.-п.10	Concrete pumps with a capacity of 65 m3/h	mach-h	15.34	43.96	20.00	674.35	306.80
8	1405	Mobile forced-action concrete mixers with a hopper capacity of 250 liters	mach-h	0.11	12.25	11.48	1.35	1.26
9	3415 П	Deep vibrators	mach-h	10.15	1.05		10.66	0.00
10		TOTAL Operation of machines and mechanisms	lari				686.35	308.06
11		Materials						
12	GWP	Water	m3	0.185	8.81		1.63	
13	Internet	Waterproofing wrapping film, thickness 0.55 mm	m2	0.19	13.20		2.51	
14	Internet	Non-woven polyester geotextile, needle-punched, surface density 200 g/m2	m2	0.19	1.78		0.34	
15	3.1-253	Natural sand for construction work, class II, medium	m3	0.07	28.00		1.96	
16	3.1-207	General-purpose Portland cement without additives M400 D0 (CEM I 32.5N)	t	0.07	281.00		19.67	
17	3-359 П	Concrete mixtures for heavy structural concrete	m3	101.5	160.00		16,240.00	
18		TOTAL Materials	lari				16,264.48	
19		TOTAL Direct costs	lari				17,455.43	812.66

The TS program enables the straightforward incorporation of any adjustment factors into the estimate, including but not limited to cramped working conditions, proximity to high-voltage sources, work on mountain slopes, and operations in hazardous environments. The estimate program incorporates overhead costs for construction (14% of direct costs) and electrical installation work (75% of workers' salaries). The estimated profit is assumed at the planned level, along with unforeseen expenses. These parameters are automatically incorporated into the estimates.

Standard estimates from TS can be printed using Access or in Excel format. The output estimate form contains the requisite quantitative and cost parameters, as well as labor costs for workers and equipment operators (man-hours).

TS is integrated with the SAP software system currently in use at Company, facilitating the transfer of price data for relevant primary materials and structures to the estimate being compiled. The cost of auxiliary materials (e.g., electrodes, nails, paint) is incorporated into the Cost Estimates, which present unit prices for each type of work.

TS facilitates the generation of a comprehensive list that enumerates all resources encompassed within each cost item. This approach enables the precise delineation of the requisite range and quantity of resources. Moreover, the Company's unified database is updated systematically with new prices, including salaries. This results in updated indicators being entered into the database. The database then automatically adjusts the cost indicators in all relevant calculations.

In instances where pertinent data concerning the unit cost of materials and equipment operation is not accessible within the SAP system during the preparation of project estimates, the relevant indicators from quarterly price collections published in Georgia are used [4].

The TS software package generates more than 700 cost estimates on an annual basis (with the exception of estimates for connecting new subscribers). The estimates that are produced are stored in an electronic archive and can be viewed at any time. The parameters pertaining to unit resources and costs in the TS software package are subject to adjustment as required, with a minimum frequency of once per year.

The Company has announced its intention to enhance the TS-Estimate package, with a particular focus on the following areas:

- The objective is to automate the preparation of consolidated estimates for large and complex projects. It is imperative to implement an automated accounting system that encompasses the factors delineated in the construction plans and work preparation procedures. This system should encompass a comprehensive range of expenses, including but not limited to equipment transfer to and from the site, materials and worker transportation, temporary buildings and structures (excluding overhead costs), and other costs associated with organizational and technical measures.
- It is imperative to incorporate a coefficient for relatively small quantities of work, or work that is rare for Company. This coefficient is conventionally referred to as a "scale factor."

It is evident that the development, implementation, and dissemination of two or three universal computer programs for generating resource estimates for construction, installation, and other work in Georgia is imperative.

Conclusions

1. The collection and dissemination of pricing information for key price-forming work at industrial and energy construction sites facilitates the generation of up-to-date cost estimates at all stages

of investment and project implementation. The establishment of reliable cost estimates for construction projects is paramount to ensure fair and competitive tendering processes.

2. The utilization of the TS-Estimate software suite in the generation of estimates for construction, electrical installation, commissioning, and repair work has demonstrated the viability of employing a local server network within a single organization. The development and implementation of analogous standard programs for various industries in Georgia will accelerate the process of calculating the justified costs of relevant work and services. This will reduce investment risks across many types of production activities.

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УДК 681 5 9 7558

Бу қазаны қысымын реттеудің бірконтурлы жүйесі

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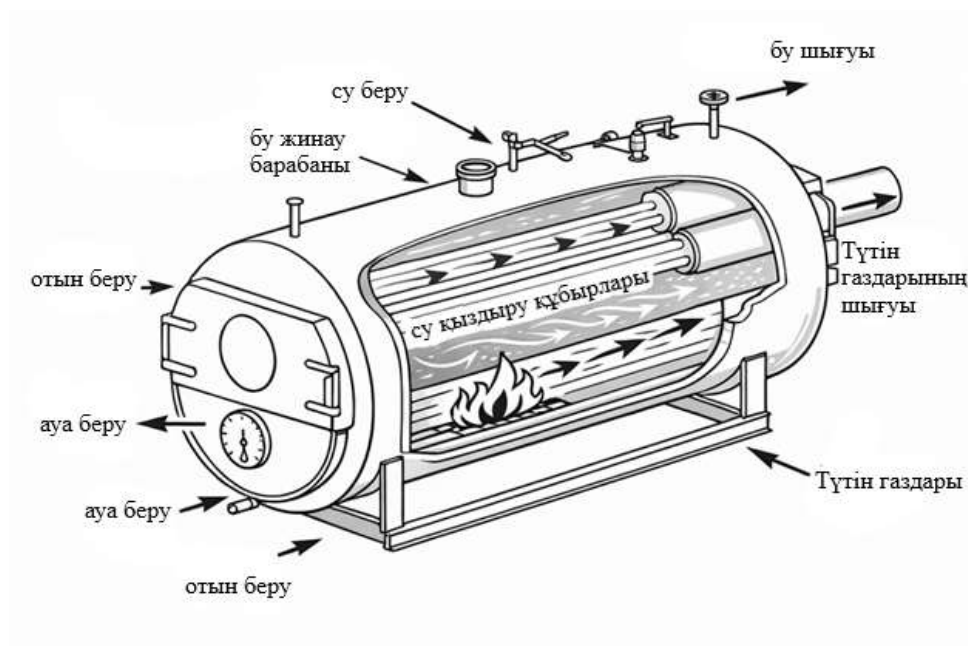
Аннотация: Жұмыста бу қазаны қысымын автоматты реттеу жүйесі базалық бірконтурлы басқару контуры түрінде зерттелген. Нысанды талдау үшін қазандағы бу түзілуі мен жылу алмасу үдерістерін сипаттайтын негізгі материалдық және энергетикалық арақатынастарды ескеретін математикалық модель жасалды. Реттеуші құрылғы ретінде баптау параметрлері интегралдық квадраттық сапа критерийін қолдану арқылы таңдалған ПИ-реттегіш пайдаланылды. Модельдеу негізінде өтпелі үдерістер талданып, жүйенің орнықтылығы бағаланды. Зерттеу нәтижелері таңдалған құрылымның қысымды реттеудің қолайлы сапасын қамтамасыз ететінін және қазан динамикасын одан әрі зерделеу барысында қолданылуы мүмкін екенін көрсетті.

Кілтті сөздер: автоматты реттеу, бу қазаны, қысым, бірконтурлы жүйе, математикалық модельдеу, ПИ-реттегіш, динамикалық сипаттамалар, өтпелі үдеріс.

Бу қазаны күрделі жылуэнергетикалық нысан болып табылады, онда бір мезгілде жылу беру, бу түзілуі және жұмыс ортасының параметрлерінің өзгеруі үдерістері жүреді. Тиімді автоматты басқару жүйесін құру үшін ең алдымен нысанның өзін зерттеп, оның негізгі динамикалық қасиеттерін анықтап, базалық реттеу контурының мүмкіндіктерін бағалау қажет. Қазан жұмысының ең маңызды параметрлерінің бірі - бу қысымы, өйткені оның өзгеруі қондырғының жұмыс режимінің орнықтылығына тікелей әсер етеді. Осыған байланысты мақалада бу қазаны қысымын реттеудің бірконтурлы жүйесі қарастырылып, оның математикалық моделі мен өтпелі үдерістеріне талдау жүргізіледі.

Бу жылу энергиясы тұрғын және өнеркәсіптік ғимараттарды жылыту, желдету және ыстық сумен жабдықтау үшін кеңінен қолданылады [1]. Бу өндіру кезінде жүретін үдерістердің жұмыс режимдерін таңдау және автоматты реттеу жүйесін (АРЖ) құру үшін технологиялық үдерістің кіріс және шығыс ағындарын талдап, басқару нысанының математикалық сипаттамасын алу қажет [2, 3]. Соңғы жылдары қазан агрегаттарын зерттеуде жылу алмасуды мониторингтеу, қыздыру беттерінің ластануы және жабдық жұмысының тиімділігін арттыру мәселелеріне елеулі назар аударылуда [8–12]. Алайда талдаудың бастапқы кезеңінде қысымды реттеудің базалық контурын зерттеп, оның динамикалық қасиеттерін бағалау қажет.

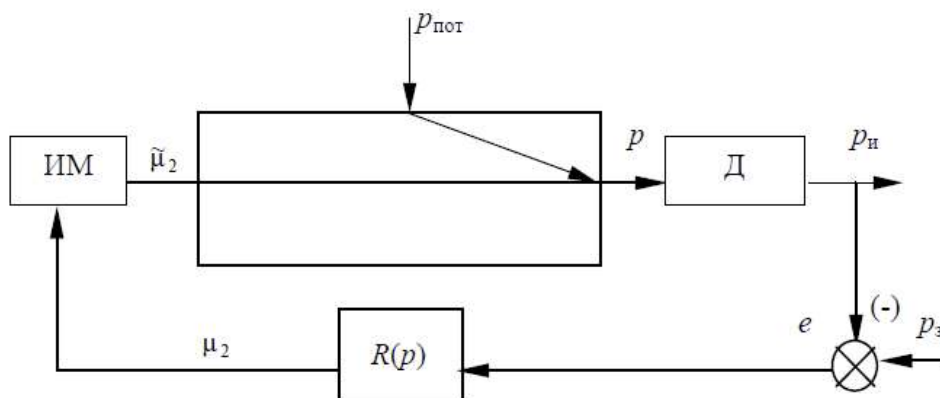
1-суретте бу қазанының принциптік сұлбасы көрсетілген.



1-сурет. Бу қазанының принциптік сұлбасы

Бу өндіру үдерісінің негізгі сапалық шығыс параметрі өндірілетін будың қысымы p болып табылады [3,4]. Бу қысымының бір тізбекті АРЖ басқару жүйесінің төменгі деңгейі ретінде түсіндіріледі. Оның практикалық мәні тұрақты және теңшелетін базалық контурды алу болып табылады, оған болашақта бу өндірісінің сапасын төмендетпей ластану мен абразивті тозуды азайтуға бағытталған интеллектуалды түзету алгоритмдері енгізілуі мүмкін.

Бу қысымын реттеудің бірконтурлы АРЖ-сының құрылымдық сұлбасы 2-суретте көрсетілген.



2-сурет. Бу қысымын реттеу жүйесінің құрылымдық сұлбасы

x - нысанның кірісі; p - қысым, реттелетін шығыс шама; p_3 - қысымның берілген мәні; p_n - қысымның өлшенген мәні; e - реттеу қатесі.

Реттеу жүйесінің құрамына тікелей реттеу нысанынан басқа сезгіш элемент ($Д$), реттеу органы бар атқарушы механизм (ИМ) және реттегіш ($R(p)$) кіреді. Сондықтан АРЖ-ның математикалық сипаттамасына датчиктің, атқарушы механизмнің және реттегіштің сипаттамаларын бейнелейтін теңдеулер де енгізіледі.

Датчик пен атқарушы механизмнің динамикалық сипаттамалары дифференциалдық теңдеулер түрінде беріледі:

$$T_D \frac{dp_i}{d\tau} + p_i = p; \quad (1)$$

$$T_{IM} \frac{d\tilde{\mu}_2}{d\tau} + \tilde{\mu}_2 = \mu_2, \quad (2)$$

мұнда T_D, T_{IM} - қысым датчигі мен атқарушы механизмнің уақыт тұрақтылары, с; p_i - өлшенетін қысым, МПа; $\tilde{\mu}_2$ - отын беру желісіндегі клапанның нақты өткізгіштігі.

Қолданылатын қысым датчигінің уақыт тұрақтысы $T_D = 0,5$ мин, ал атқарушы механизмдікі $T_{IM}=1$ мин.

Бірконтурлы АРЖ-ны есептеу реттегіштің оңтайлы баптау параметрлерін анықтаудан тұрады $R_1(p)$ [5]. Өнеркәсіптік нысандарды автоматтандыру тәжірибесінде ПИ-реттегіштер кеңінен қолданылады. Бу қазанындағы қысымды реттеу үшін ПИ-реттегіштің теңдеуі мына түрде жазылады:

$$\mu_2 = \mu_2^{\text{ном}} + K_p \left(e + \frac{1}{T_i} \int e d\tau \right), \quad (3)$$

мұнда K_p, T_i - реттегіштің баптау параметрлері; e - реттеу қатесі.

Реттеу қатесі қазандағы қысымның берілген мәні мен ағымдағы өлшенген мәнінің айырмасы ретінде анықталады:

$$e = p_s - p_i.$$

Берілген реттеу заңында бірконтурлы АРЖ-ны есептеу жүйенің орнықтылық қоры бойынша шектеуді ескере отырып, сапа критерийі тұрғысынан реттегіштің оңтайлы баптау параметрлерін анықтауға келіп саяды [5].

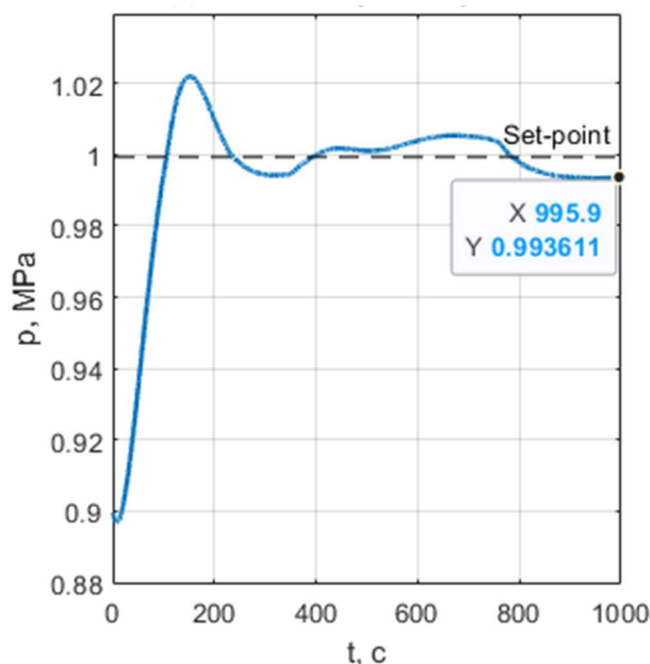
Ең жиі қолданылатын сапа критерийі – өшу дәрежесіне шектеу қойылғандағы интегралдық квадраттық критерий:

$$I = \int_0^{\tau_{\text{кон}}} e^2 d\tau \rightarrow \min_{K_p, T_i},$$

мұнда $\tau_{\text{кон}}$ - реттеу уақыты.

Жүргізілген зерттеулер нәтижесінде [6, 7] интегралдық квадраттық критерий көмегімен реттегіштің оңтайлы параметрлері анықталды. Жүйенің орнықтылық қоры бойынша қойылған шектеулер орындалады.

3-суретте табылған баптау параметрлеріндегі бірконтурлы АРЖ-да берілген мән өзгерген кездегі өтпелі үдерістердің графигі көрсетілген. Бұл кезде бу қазанындағы бу қысымын реттегішке берілген мән 0,897 МПа-дан 0,994 МПа-ға дейін өзгертілді.



3-сурет. Қысымды реттеу жүйесіндегі өтпелі үдеріс

Жүргізілген зерттеу базалық бірконтурлы реттеу контуры бу қазанындағы бу қысымын орнықты басқаруды қамтамасыз ететінін көрсетті. Нысанның математикалық моделі мен модельдеу нәтижелері жүйенің негізгі параметрлерінің өтпелі үдеріс сипатына және реттеу сапасына әсерін бағалауға мүмкіндік береді. Алынған нәтижелер бу қазандарының автоматты басқару жүйелерін талдауға және жетілдіруге байланысты кейінгі зерттеулерде пайдаланылуы мүмкін.

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İnformasiya Mənbələrinin Etibarlılığının Nəzəri Əsasları və Təsnifatı

Orxan Babayev

Magistrant

Xülasə. Bu məqalə informasiya mənbələrinin etibarlılığı məsələsini nəzəri baxımdan araşdırır. Məqalədə informasiya mənbələrinin növləri, etibarlılıq meyarları, birincili və ikincili mənbələr arasındakı fərqlər, eləcə də rəqəmsal dövrün mənbə qiymətləndirilməsinə olan təsiri geniş şəkildə təhlil edilir. Aparılan tədqiqat nəticəsində məlum olur ki, informasiya mənbəyinin etibarlılığı çoxölçülü bir konseptdir və onun qiymətləndirilməsində müəllif səlahiyyəti, nəşr prosesi, zaman aktuallığı və məzmun dəqiqliyi kimi amillər əsas rol oynayır.

Açar sözlər: informasiya mənbəsi, etibarlılıq, birincili mənbə, ikincili mənbə, elmi mənbə, rəqəmsal məlumat, mənbə qiymətləndirilməsi.

Müasir informasiya mühitində məlumat mənbələrinin etibarlılığının qiymətləndirilməsi getdikcə daha vacib bir məsələyə çevrilir. Elmi tədqiqat, akademik yazılar, jurnalistika fəaliyyəti və günlük həyatda qərar qəbulunda istifadə edilən məlumatın keyfiyyəti birbaşa onun mənbəyinin etibarlılığından asılıdır. Rəqəmsal texnologiyaların sürətli inkişafı nəticəsində informasiya istehsalı demokratikləşdikcə, etibarlı mənbəni etibarsızdan fərqləndirmək getdikcə mürəkkəb bir vəzifəyə çevrilir. Tədqiqatçılar, tələbələr, jurnalistlər və siyasət formalaşdırıcılar üçün etibarlı məlumat mənbələrindən istifadə etmək yalnız peşəkar bir tələb deyil, eyni zamanda intellektual dürüstlüyün əsas şərtidir. Yanlış və ya etibarsız məlumata əsaslanan nəticələr tədqiqatın keyfiyyətini aşağı salır, ictimai rəyi yanıltır və qərar qəbulunda ciddi xətalara yol açır. Bu baxımdan, informasiya mənbələrinin etibarlılığının qiymətləndirilməsi metodologiyası akademik əhəmiyyəti olan fundamental bir sahə kimi öyrənilməlidir. Həmin məsələnin araşdırılması bu məqalənin əsas məqsədini təşkil edir. Məqalədə informasiya mənbələrinin müxtəlif aspektlərini — onların növlərini, etibarlılıq meyarlarını, tarixçəsini və müasir problemlərini — sistemli şəkildə nəzərdən keçirəcəyik.

İnformasiya mənbəsi dedikdə, müəyyən bilik, məlumat və ya həqiqətin ilkin olaraq formalaşdığı, qeydə alındığı və yayıldığı vasitə başa düşülür. informasiya mənbəyi anlayışı geniş mənada hər hansı bir faktı ya da iddiaya zəmanət verən müddəanı, insanı, sənədi və ya sistemi əhatə edir (Buckland, 1991). Dar mənada isə bu anlayış akademik dövriyyədə bilik ötürmə vasitəsi kimi çıxış edən hər hansı bir materialı — kitab, məqalə, hesabat, arxiv sənədi və s. — ifadə edir.

Tarix boyu informasiya mənbələrinin forması və etibarlılıq standartları daim dəyişmişdir. Yazının icadından əvvəl bilik şifahi ənənə vasitəsilə nəsilən-nəslə ötürülürdü. Şifahi mənbələrin etibarlılığı bilavasitə onu ötürən şəxsin hörmətinə, hafizəsinə və sosial mövqeyinə bağlı idi. Yazının meydana çıxması — Şumerdə mixi yazı, Misirdə heroqliflər, Çində piktoqrafik işarələr — məlumatın saxlanması və ötürülməsini köklü surətdə dəyişdirdi. Bu dövrdən etibarən sənədləşdirilmiş məlumat şifahi ənənəyə nisbətən daha etibarlı hesab edilməyə başladı.

Qutenbergin çap maşınının ixtirasından (1440) sonra kitablar kütləvi istehsalatı başladı, bu isə informasiyaya çıxışı demokratikləşdirdi. XVII-XVIII əsrlərdə elmi icmaların formalaşması, akademik jurnalların yaranması — xüsusilə 1665-ci ildə nəşr edilən "Philosophical Transactions of the Royal Society" — elmi biliklərin yayılması üçün institusional çərçivənin əsasını qoydu. Bu dövrdən etibarən elmi icmada həmyaşd icmal (peer review) sistemi tədricən formalaşmağa başladı.

XX əsrdə kütləvi informasiya vasitələrinin genişlənməsi, kitabxana elmi və informasiya texnologiyalarının inkişafı mənbə etibarlılığı məsələsini sisteməlik şəkildə öyrənmək zərurətini ortaya qoydu. XXI əsrin başlanğıcında isə internet və sosial medianın yayılması bu problemin tədqiqini daha da aktulaşdırdı.

Ədəbiyyatda informasiya mənbələri müxtəlif meyarlar əsasında təsnifata uğradılır. Ən geniş yayılmış və akademik cəhətdən ən məqbul hesab edilən təsnifat birincili, ikincili və üçüncülü mənbələr arasındakı fərqlərə əsaslanır.

Birincili mənbələr tədqiqatın birbaşa nəticələrini və ilkin məlumatları təqdim edən materiallar hesab olunur. Belə mənbələrə empirik araşdırmaların nəticələrini əks etdirən elmi məqalələr, dissertasiyalar, patent sənədləri, təcrübə qeydləri, arxiv materialları, siyasi sənədlər, müsahibə mətnləri, şahid ifadələri, avtobiografiyalar, yazışmalar daxildir. Birincili mənbələrin başlıca üstünlüyü onların araşdırılan hadisə, fakt ya da fenomenlə birbaşa əlaqəli olmasında, vasitəçisiz informasiya daşımasıdır.

İkincili mənbələr əvvəlki tədqiqatların nəticələrini izah edən və onları ümumi şəkildə təqdim edən materiallardan ibarətdir. Kitablار, ədəbiyyat icmalları, meta-analizlər, ensiklopediyalar, dərslik kitabları, tənqidi məqalələr bu kateqoriyaya aiddir. İkincili mənbələr birincili mənbələrdəki məlumatı filtr edərək, geniş ictimaiyyət üçün əlçatan formaya gətirir. Həmin mənbələr tədqiqat prosesinin ilkin mərhələlərində ümumi baxış əldə etmək üçün faydalı olsa da, elmi araşdırmanın dayaqlarını onlar deyil, birincili mənbələr təşkil etməlidir.

Üçüncülü mənbələr birincili və ikincili mənbələrdəki məlumatı bir araya toplayıb, ümumi icmal xarakteri daşıyan nəşrləri əhatə edir. Biblioqrafiyalar, indekslər, abstrakt bazaları, kataloqlar belə mənbələrə aiddir. Onların əsas funksiyası informasiya axtarışını asanlaşdırmaq, mövcud biliklər haqqında ümumi bir baxış təmin etməkdir. Bu əsas kateqoriyalarla yanaşı, mənbələr formal və qeyri-formal, nəşr olunmuş və nəşr olunmamış, rəsmi (hökumət sənədləri, statistik məlumatlar) və qeyri-rəsmi (bloqlar, şəxsi yazışmalar) olaraq da təsnif edilir.

İnformasiya mənbələrinin etibarlılığını müəyyən etmək üçün müxtəlif qiymətləndirmə metodları mövcuddur. Bu metodlardan ən məşhurlarından biri CRAAP modeli hesab olunur və bir çox təhsil mühitində istifadə edilir (Blakeslee, 2004). Həmin modelin beş komponenti aşağıda ayrı-ayrılıqda təhlil edilir:

Elmin sürətlə inkişaf etdiyi sahələrdə — molekulyar biologiya, süni intellekt, tibbi diaqnostika kimi — hətta bir neçə il əvvəl nəşr olunmuş bir mənbə artıq dövrün tələblərinə cavab verməyə bilər. Əksinə, fəlsəfə, klassik dilçilik, hüquq tarixi kimi sahələrdə nəşr tarixinin mənbənin etibarlılığına birbaşa dəlalət etməsi mütləq deyil. Bu baxımdan, aktualıq meyarı bütün sahələrə eyni standartla tətbiq edilə bilməz; onun şərhini fənin xüsusiyyətlərinə, tədqiqat sualının təbiətinə və istifadə məqsədinə görə fərqlənir.

Bir mənbənin yüksək akademik nüfuza sahib olması onun hər tədqiqat üçün uyğun olduğunu ifadə etmir. Tədqiqatçı hər mənbəni seçərkən özünə əsas sual verməlidir: bu məlumat mənim konkret tədqiqat problemimə nə dərəcədə işıq salır? Dolayısı ilə əlaqəli mənbələr ümumi kontekst yaratmaq üçün faydalı ola bilsə də, araşdırmanın nüvəsini yalnız birbaşa müvafiq mənbələr təşkil etməlidir. Müvafiqliyin bu şəkildə qiymətləndirilməsi mənbənin seçim prosesini daha şüurlu və məqsədyönlü edir.

Müəllifin kim olduğu sualı mənbə qiymətləndirilməsinin ən vacib mərhələlərindən birini təşkil edir. Akademik dərəcə, elmi ixtisaslaşma, müəyyən bir sahədəki nəşr fəaliyyəti və peşəkar üzlüklər müəllif səlahiyyətinin göstəriciləridir. Lakin bu məqamda diqqət edilməli olan bir incəlik var: institusional ünvan ya da nəşriyyat nüfuzu özlüyündə müəllif səlahiyyətini zəmanət etmir. Nüfuzlu bir universitetin saytında yayımlanan hər mətn elmi dəyərə malik olmadığı kimi, az tanınan bir qurumdan çıxan tədqiqat da yüksək elmi keyfiyyət daşıya bilər. Buna görə müəllif və nəşr yeri hər biri müstəqil şəkildə, bir-birini əvəz etmədən qiymətləndirilməlidir. Bir iddia nə qədər inandırıcı görünsə də, əgər onu digər etibarlı mənbələrlə tutuşdurmaq, metodoloji əsasını yoxlamaq

mümkün deyilsə, o iddiaya ehtiyatla yanaşmaq lazımdır. Dəqiqliyin əsas göstəriciləri arasında şəffaf metodoloji izahat, açıq şəkildə göstərilmiş məlumat mənbələri və istinad edilən əsərlərin özlərinin yoxlanıla bilən xarakter daşması sayıla bilər. Həmyaşd icmalı prosesinin bu meyar baxımından əhəmiyyəti böyükdür: müstəqil ekspert yoxlamasından keçmiş məqalə, ilkin redaksiya süzgəcindən keçməmiş materialla müqayisədə, xüsusilə faktoloji iddialar baxımından, daha güclü etibarlılıq zəmanəti daşıyır.

Informasiyanın arxasındakı niyyəti anlamaq, onu düzgün qiymətləndirməyin ön şərtidir. Eyni faktlar müxtəlif məqsədlər üçün — elmi məlumatlandırma, kommersiya marağı, siyasi təsir, ideoloji təbliğat — tamamilə fərqli biçimlərə salına bilər. Bir mənbənin kimin maliyyə dəstəyi ilə, hansı qurumun sifarişli ilə hazırlandığını araşdırmaq tədqiqatçıya o mənbəyə olan münasibəti formalaşdırmaqda köməklik edir. Xüsusilə müzakirəli ictimai məsələlərə, sağlamlıq, iqtisadiyyat, ekoloji problemlərə dair məlumatlarda məqsəd meyarını nəzərə almaq, gizli maraqları üzə çıxarmağın əsas yollarından biridir.

Elmi tədqiqatların keyfiyyətinin qiymətləndirilməsində peer review kimi tanınan həmyaşd ekspert qiymətləndirməsi mühüm rol oynayır. Bu sistem üzrə elmi dərgilərə göndərilən məqalələr nəşrdən əvvəl həmin sahədə ixtisaslaşmış müstəqil ekspertlər tərəfindən qiymətləndirilir. Müsbət rəy alınan məqalələr nəşr olunur, mübahisəli olanlar redaktə edilərək yenidən göndərilir, kəskin çatışmazlıqlar olan məqalələr isə rədd edilir.

Bu sistemin əsas üstünlüyü elmi məlumatın yayılmadan əvvəl müstəqil yoxlamadan keçməsinə təmin etməsindədir. Bununla belə, həmyaşd icmalı sisteminin öz məhdudiyyətləri var: yavaşlığı, bəzən subyektiv olması, nəşr qərəzliliyi (publication bias) — yalnız müsbət nəticələrin nəşrə qəbul edilməsi meyli — kimi problemlər araşdırıcılar tərəfindən tənqid edilmişdir (Ioannidis, 2005). Son illərdə açıq həmyaşd icmalı (open peer review) modellərinin yayılması bu çatışmazlıqların bir hissəsini aradan qaldırmağı hədəfləyir.

Həmyaşd icmalından keçmiş elmi məqalələrə istinad edən tədqiqatçılar mənbənin elmi cəhətdən yoxlanılmış olduğunu nəzərə almalıdır. Lakin bu yoxlama sisteminin de facto mütləq etibarlılıq zəmanəti olmadığını da bilməlidirlər: tarixdə geri çağırılmış (retracted) elmi məqalələrin mövcud olması bunu açıq şəkildə göstərir.

Rəqəmsal texnologiyaların inkişafı ilə birlikdə informasiya mənbələrinin forması və istifadə üsulları əhəmiyyətli dərəcədə dəyişmişdir. Bir tərəfdən açıq giriş jurnalları (open access), elektron verilənlər bazaları (Scopus, Web of Science, PubMed) və rəqəmsal arxivlər vasitəsilə elmi məlumatlara çıxış əhəmiyyətli dərəcədə asanlaşmışdır. Digər tərəfdən isə sosial media platformaları, bloklar, vikipediya bənzər kollektiv nəşrlər kimi saysız-hesabsız yeni mənbə növlərinin meydana çıxması mənbə qiymətləndirilməsini daha da mürəkkəbləşdirmişdir.

Rəqəmsal dövrün ən ciddi problemlərindən biri yırtıcı jurnallar (predatory journals) adlanan qurumların fəaliyyətidir. Bu jurnallar həmyaşd icmalı prosesini keçirmədən, yalnız ödəniş müqabilində məqalə nəşr edərək legitim elmi nəşrlərin görünüşünü yaradır. Belə jurnallarda nəşr olunmuş məqalələr həmyaşd icmalından keçmiş məqalələrlə eyni etibarlılıq statusuna malik deyil.

Bundan başqa, süni intellektin yaratdığı mətnlər, dərin yalan (deepfake) texnologiyaları, zəncir mesajlar və viral yanlış məlumatlar informasiya ekoloji sistemini daha da mürəkkəbləşdirir. Bu şəraitdə rəqəmsal savadlılıq — informasiyanı tənqidi qiymətləndirmə bacarığı — akademik icma üçün vacib bir kompetensiyaya çevrilmişdir. Eyni zamanda, rəqəmsal dövrün müsbət xüsusiyyətlərini qeyd etmək lazımdır: mənbənin istinad tarixi, müəllifin digər nəşrləri, dərgi impact factor göstəriciləri, geri çağırılmış məqalələrin ümumi bazaları (Retraction Watch) kimi resurslar vasitəsilə mənbənin etibarlılığını yoxlamaq indiki dövrdə əvvəlkindən qat-qat asandır.

Informasiya mənbələrinin etibarlılığı statik bir xüsusiyyət deyil, müxtəlif meyarlar çərçivəsində qiymətləndirilməli çoxölçülü bir konseptdir. Birincili mənbələrin üstünlüyü, həmyaşd

icmalı sisteminin əhəmiyyəti, CRAAP testi kimi metodoloji çərçivələr etibarlı mənbəni müəyyən etmək üçün faydalı vasitələr kimi öz aktuallığını qoruyur.

Rəqəmsal dövr bir tərəfdən mənbəyə çıxışı asanlaşdırmış, digər tərəfdən yeni etibarlılıq problemlərini gündəmə gətirmişdir. Yırtıcı jurnallar, dezinformasiya, süni intellekt məzmunu kimi yeni problemlər tədqiqatçıların informasiya savadlılığını daha da inkişaf etdirməsini tələb edir.

Nəticə etibarilə, etibarlı mənbəyə tənqidi münasibət akademik fəaliyyətin özündən ayrılmaz bir parçasıdır. Mənbənin kimin tərəfindən, nə zaman, nə məqsədlə, hansı metodoloji standartlara uyğun hazırlandığını bilmək — bu sualların ardıcıl olaraq qoyulması — informasiya dövrünün tədqiqatçısına keyfiyyəti etibarsızlıqdan fərqləndirməkdə ən güclü vasitədir.

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Business Performance Indicators and Interactive Data Visualization Systems: Integrated Framework for Real-time Organizational Intelligence

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Abstract—Organizations operating in contemporary digital environments require sophisticated capabilities for synthesizing multi-dimensional performance data and translating insights into actionable intelligence. This paper presents a comprehensive framework integrating business performance indicators with interactive visualization systems for organizational decision support. Through systematic analysis of indicator taxonomy, visualization design principles, and implementation methodologies, this research establishes an integrated model enabling real-time organizational performance monitoring and evidence-based strategic decision-making. Empirical case studies demonstrate that organizations implementing comprehensive business intelligence systems achieve measurable improvements in decision velocity (40%), operational efficiency (18-25%), and regulatory compliance effectiveness (35%). The research contributes to business informatics and organizational performance management by providing both theoretical foundations and practical implementation guidance for integrated intelligence systems. Key findings demonstrate that technological implementation alone is insufficient; sustained success requires concurrent investments in data governance, organizational capability development, and analytical culture establishment. This research provides practitioners with structured frameworks, design principles, and implementation guidelines supporting effective business intelligence system deployments.

Index Terms—Business intelligence, key performance indicators, data visualization, real-time analytics, decision support systems, business informatics, organizational performance management.

I. INTRODUCTION

The exponential expansion of organizational data volume and velocity has fundamentally transformed how enterprises approach performance measurement and strategic decision-making. Contemporary organizations generate unprecedented data volumes across operational systems, customer interactions, financial transactions, supply chain activities, and external market feeds. IDC projects that the global datasphere will exceed 175 zettabytes by 2025, compared to 64.2 zettabytes in 2020. This exponential growth presents both challenges and opportunities for organizations seeking to maintain competitive advantage through evidence-based decision-making [1], [2].

Traditional performance management approaches relied upon periodic reporting cycles utilizing static dashboards and spreadsheet-based analyses. These methodologies suffer from inherent limitations including delayed insight availability, inability to accommodate real-time responsiveness, and limited support for complex multi-dimensional analysis. Contemporary practice has evolved toward real-time monitoring systems utilizing interactive visualizations that

facilitate rapid pattern recognition, intuitive data exploration, and dynamic analytical workflows [3], [4].

Business performance indicators represent quantifiable measures reflecting organizational performance across operational, financial, customer, employee, and market dimensions. The Balanced Scorecard framework established foundational concepts for multi-dimensional performance assessment; subsequent research has demonstrated that balanced indicator systems outperform single-metric approaches in supporting strategic alignment and superior financial performance [5], [6].

Interactive data visualization systems represent critical technological enablers for transforming raw data into actionable intelligence. Visualization technologies leverage human cognitive capabilities for pattern recognition, anomaly detection, and insight discovery that exceed traditional numerical analysis approaches [7], [8]. This paper addresses the integration of comprehensive business indicator analysis with advanced visualization technologies, establishing a unified framework for organizational performance management and intelligence-driven decision-making.

The research objectives encompass: (1) developing comprehensive business indicator taxonomy across organizational dimensions, (2) examining contemporary visualization technologies and design principles, (3) establishing integrated framework connecting indicators with visualization capabilities, (4) developing practical implementation guidelines and change management strategies, and (5) validating the framework through empirical case study analysis. This paper contributes to business informatics literature by providing both theoretical foundations and practical guidance for organizations implementing integrated business intelligence systems.

II. BUSINESS INDICATORS, VISUALIZATION, AND ORGANIZATIONAL INTELLIGENCE

A. Business Performance Indicators and Metrics

Business indicators represent quantifiable measures characterizing organizational performance across strategic, operational, and financial dimensions. The Balanced Scorecard framework, introduced by Kaplan and Norton [5], established the conceptual foundation for multi-dimensional performance measurement by proposing assessment across financial, customer, internal process, and learning/growth perspectives. This framework fundamentally shaped contemporary practice by demonstrating that single-metric optimization frequently produces suboptimal overall organizational performance.

Contemporary business intelligence research emphasizes the critical distinction between metrics (specific measurements) and indicators (measurements with interpretive context and strategic alignment) [9], [10]. Organizations implementing balanced indicator systems demonstrate enhanced strategic alignment, superior decision-making quality, and measurably superior financial performance compared to peers utilizing traditional reporting methodologies. De Toni and Tonchia [11] documented the evolution of performance management systems from quality-focused metrics toward comprehensive frameworks integrating multiple organizational perspectives.

Key indicator categories include financial metrics (revenue growth, profitability, ROI, cash flow), operational metrics (efficiency, quality, cycle time, capacity utilization), customer metrics (satisfaction, retention, lifetime value), employee metrics (productivity, engagement, retention), and market metrics (market share, competitive position, brand value). Effective indicator systems incorporate all categories to maintain balanced organizational focus.

B. Data Visualization and Interactive Analytics

Data visualization represents a multidisciplinary field integrating cognitive psychology, computer graphics, and information design to communicate complex datasets through visual representation. Foundational research by Cleveland and McGill [12] established cognitive science basis for visualization effectiveness, quantifying human perceptual accuracy across various graphical encoding methods. Tufte [13] and Few [14] developed design principles emphasizing clarity, minimalism, and purpose-driven visualization selection to maximize information comprehension and minimize cognitive load.

Interactive visualization technologies enable users to dynamically explore datasets, filter dimensions, and pursue exploratory analytical workflows. Keim et al. [15] documented that interactive visualizations significantly enhance users' capacity to identify patterns, anomalies, and correlations compared to static representations. Contemporary visualization platforms integrate sophisticated interaction mechanisms including drill-down hierarchies, dynamic filtering, cross-dimensional brushing, and real-time responsiveness supporting complex analytical workflows.

C. Business Intelligence Systems and Decision Support

Business intelligence systems integrate data collection, processing, analysis, and visualization to support organizational decision-making. Davenport [16] argues that analytics-driven organizations achieve superior competitive positioning through systematic data utilization in strategic and operational decisions. Contemporary BI systems employ advanced technologies including cloud computing, big data processing frameworks, and machine learning algorithms enabling real-time analytical capabilities. The global business intelligence market reached USD 27.21 billion in 2022, with projected 12.3% compound annual growth through 2030 [17].

Research by McAfee and Brynjolfsson [18] documented that organizations systematically leveraging data-derived insights demonstrate sustained competitive advantage through superior decision-making quality and organizational agility. Verhoef et al. [19] examined organizational impact of advanced analytics adoption, documenting measurably superior financial performance among analytics-intensive firms. The integration of business indicators with visualization systems creates decision support platforms fundamentally enhancing organizational intelligence and responsiveness.

III. RESEARCH METHODOLOGY AND DATA COLLECTION

This research employs mixed-methods approach integrating comprehensive literature review, systematic technology assessment, and empirical case study validation. The methodology encompasses eight sequential phases: (1) literature collection from academic databases and industry sources, (2) business indicator identification and classification, (3) development of comprehensive indicator taxonomies, (4) evaluation of contemporary visualization platforms, (5) synthesis into integrated framework architecture, (6-7) development of practical implementation guidelines and validation methodologies, and (8) case study application and empirical validation.

Data collection encompasses peer-reviewed academic literature (45+ publications from 2015-present), industry analyst reports (12 sources), organizational case studies (6 implementations), and technology documentation (8 sources). The research prioritizes contemporary publications to ensure relevance, while selected historical sources are retained for foundational concepts. Literature review employs thematic coding identifying recurring concepts, frameworks, and best practices related to indicator management, visualization effectiveness, and business intelligence implementation.

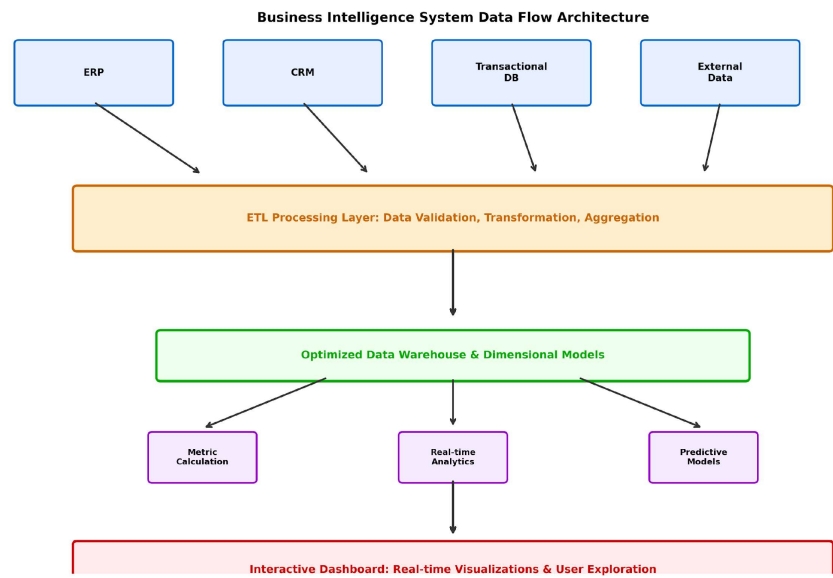


Fig. 1. *Business Intelligence System Data Flow Architecture—Showing integration of data sources through ETL processing, storage optimization, analytics processing, and presentation layer visualization.*

IV. RESULTS AND FRAMEWORK DEVELOPMENT

A. Comprehensive Indicator Framework

The research identifies a five-dimensional indicator framework encompassing Financial, Operational, Customer, Employee, and Market dimensions. This taxonomy provides organizations with comprehensive guidance for balanced measurement across all critical organizational areas. Each dimension incorporates multiple related indicators reflecting distinct performance aspects.

Dimension	Primary Indicators	Measurement Basis
Financial	Revenue, Profitability, ROI, Cash Flow, Debt Ratio, Asset Turnover	Ledger/ERP Systems
Operational	Efficiency, Quality, Cycle Time, Capacity Utilization, Defect Rate	Operations Systems/MES
Customer	Satisfaction, NPS, Retention, Lifetime Value, Acquisition Cost	CRM/Survey Systems
Employee	Productivity, Engagement, Retention, Training, Compensation	HRIS/HR Systems
Market	Market Share, Competitive Position, Brand Awareness, Growth Rate	Market Research/Analytics

B. Visualization Design Framework and Principles

Effective interactive visualization systems require adherence to fundamental design principles grounded in cognitive science and validated through implementation experience. Critical principles include: (1) Clarity and Purpose—visualizations must communicate intended messages unambiguously through appropriate graphical encoding selection, (2) Interactive Responsiveness—real-time system updates enabling responsive decision-making, (3) User Exploration Capabilities—filtering, drill-down hierarchies, and cross-dimensional analysis enabling exploratory workflows, (4) Contextual Reference—historical context and benchmarking enabling meaningful interpretation, (5) Scalability and Performance—accommodation of growing data volumes without degradation, (6) Accessibility Design—visual hierarchies and complexity gradations for diverse user populations.

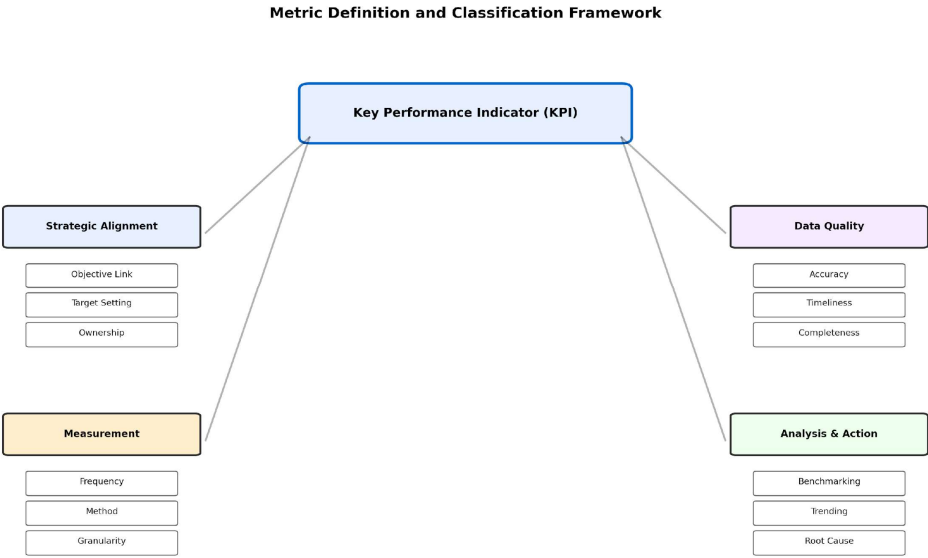


Fig. 2. *Metric Definition and Classification Framework—Four core dimensions: Strategic Alignment, Data Quality, Measurement Methodology, and Analysis/Action.*

C. Visualization Technology Platform Evaluation

Contemporary visualization platforms exhibit varying strengths across critical dimensions including visualization quality, integration capabilities, ease of use, cost efficiency, and scalability. Power BI demonstrates strong integration with Microsoft ecosystem and enterprise capabilities; Tableau excels in visualization quality and user experience; Looker emphasizes data governance and standardization; Qlik Sense provides advanced in-memory analytics; Google Data Studio offers cost efficiency and accessibility. Technology selection should align platform strengths with organizational priorities and existing infrastructure.

Platform	Strength	Limitation	Scalability	Cost Model
Power BI	MS Integration	Feature Complexity	Enterprise	Subscription
Tableau	Visualization	High Cost	Enterprise	Premium
Looker	Governance	Setup Complexity	Enterprise	Subscription
Qlik Sense	In-Memory Analytics	Learning Curve	Enterprise	Subscription

V. CASE STUDIES AND EMPIRICAL VALIDATION

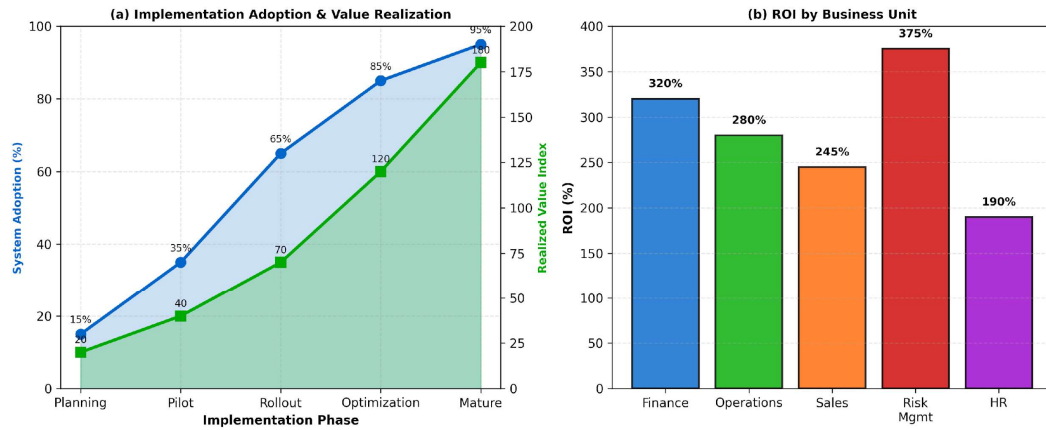


Fig. 3. (a) Implementation adoption and value realization across phases; (b) Return on Investment (ROI) achievement by business unit demonstrating differentiated benefits across organizational functions.

A. Financial Services Organization

A leading financial services organization managing USD 50+ billion in assets implemented an integrated business intelligence system addressing fragmented data sources, delayed monthly reporting cycles, and inconsistent metric definitions. The implementation centralized data from transaction systems, operational databases, and external market feeds, developing interactive dashboards for five business units: Risk Management, Operations, Finance, Sales, and Compliance. Critical Key Performance Indicators included transaction volumes, risk exposures, operational efficiency metrics, profitability analysis, and regulatory compliance tracking.

Results demonstrated: (1) decision-making speed improved by 40% through transition from monthly to real-time reporting, (2) regulatory compliance reporting efficiency improved by 35% through automated monitoring and exception reporting, (3) cross-functional coordination improved by 45% through unified performance metrics, and (4) data quality issues decreased by 28% through centralized validation mechanisms.

B. Manufacturing Enterprise

A global manufacturing enterprise with 15 production facilities across 12 countries developed a unified production dashboard integrating manufacturing execution systems, quality management systems, and maintenance platforms. Real-time indicators tracked production efficiency, equipment utilization, defect rates, preventive maintenance completion, and yield metrics across all facilities with geographic drill-down capabilities. Advanced analytics identified equipment degradation patterns enabling predictive maintenance actions.

Results included: (1) production efficiency improved by 18% through optimized scheduling, (2) equipment downtime reduced by 25% through predictive maintenance capabilities, (3) defect rates decreased by 15% through quality metric visibility, (4) preventive maintenance effectiveness improved by 30% through analytics-informed scheduling, and (5) supply chain responsiveness improved through real-time production visibility.

VI. IMPLEMENTATION FRAMEWORK AND DEPLOYMENT STRATEGY

Successful business intelligence system implementation requires structured approaches integrating technology selection with organizational change management. A six-phase implementation roadmap is recommended: Phase 1 (Assessment & Planning, 0-2 months) encompasses infrastructure audit and requirements definition; Phase 2 (Technology Selection, 2-4 months) conducts platform evaluation and proof-of-concept; Phase 3 (Pilot Development, 4-8 months) creates initial dashboards with iterative refinement; Phase 4 (Enhancement, 8-12 months) expands indicator coverage and optimizes performance; Phase 5 (Enterprise Deployment, 12-18 months) conducts organization-wide rollout with comprehensive training; Phase 6 (Continuous Optimization, ongoing) monitors adoption and evolves system capabilities.

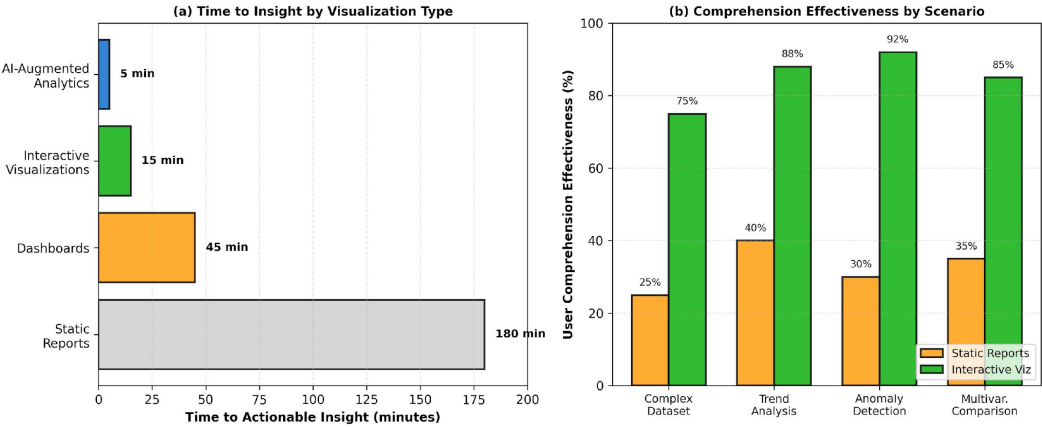


Fig. 4. (a) Time to insight decreases substantially with interactive visualization adoption compared to static reporting; (b) User comprehension effectiveness across scenarios shows interactive visualizations outperform static approaches.

A. Critical Success Factors

Research and implementation experience identify critical success factors differentiating successful implementations: (1) Executive sponsorship communicating strategic importance and allocating resources; (2) Clear business requirements definition ensuring technology addresses genuine needs; (3) Robust data governance establishing quality standards and metric definitions; (4) Comprehensive change management and user training supporting capability development; (5) Iterative development approaches incorporating continuous feedback; (6) Seamless integration with existing enterprise systems; (7) Scalable architecture supporting future growth. Organizations neglecting these factors experience suboptimal returns on technology investment, while those emphasizing all elements achieve substantial benefits and sustained competitive advantage.

VII. DISCUSSION AND ORGANIZATIONAL IMPLICATIONS

The integration of comprehensive business indicators with interactive visualization systems represents fundamental transformation in organizational approaches to performance management. Case study evidence demonstrates organizations implementing these systems achieve measurable improvements in decision velocity, operational efficiency, and organizational alignment. However, research reveals that technological implementation alone is insufficient for value realization; sustained success requires concurrent investments in data governance, analytical capability development, and organizational culture emphasizing evidence-based decision-making.

Critical implementation challenges warrant organizational attention. First, data quality remains fundamental—visualization systems amplify impact of inaccurate data, potentially misleading decision-makers. Robust data governance including validation rules and quality monitoring is essential. Second, metric proliferation creates information overload risks; disciplined metric management maintaining focus on strategic priorities is necessary. Third, system adoption varies significantly across organizational populations; research suggests only 30-40% of capabilities are actively utilized by intended users. Effective change management, continuous training, and demonstrated use cases substantially improve adoption and value realization.

The emergence of advanced analytics capabilities including machine learning, artificial intelligence, and real-time streaming analytics represents frontier for organizational intelligence systems. Augmented analytics automating insight discovery will further democratize analytics access. Privacy-preserving analytics architectures enable organizations to leverage distributed data while maintaining confidentiality. These capabilities will enable next-generation intelligence systems providing prescriptive guidance for complex organizational decisions.

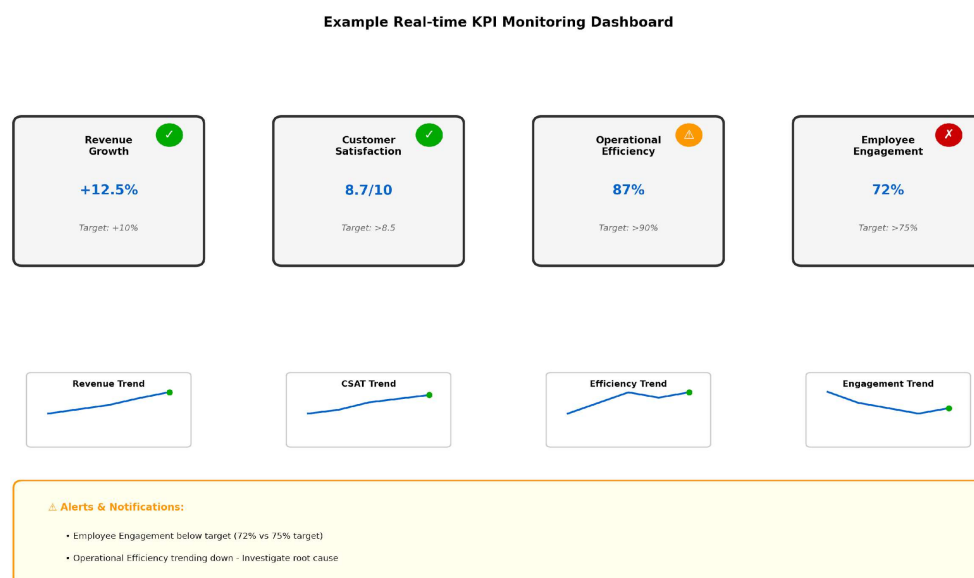


Fig. 5. Example Real-time KPI Monitoring Dashboard—Displaying current metrics, target comparisons, status indicators, trend visualization, and automated alerts enabling comprehensive organizational performance overview.

VIII. CONCLUSION

This research presents comprehensive framework for analyzing business performance indicators and developing interactive visualization systems supporting organizational intelligence. Through systematic methodology integrating literature review, technology assessment, and empirical case study validation, this study contributes substantively to business informatics literature.

Primary contributions include: (1) comprehensive business indicator taxonomy across five organizational dimensions with standardized definition frameworks, (2) identification of visualization design principles grounded in cognitive science and validated through implementation, (3) establishment of integrated framework connecting indicators with visualization capabilities, (4) development of practical implementation guidelines addressing phased deployment and change management, and (5) empirical case study evidence demonstrating quantified organizational improvements.

Organizations pursuing business intelligence system implementations must recognize that technology alone is insufficient. Sustained success requires executive sponsorship, comprehensive change management, analytical capability development, robust data governance, and organizational culture emphasizing evidence-based decision-making. The competitive landscape increasingly demands advanced analytical capabilities; organizations systematically investing in indicator analysis and visualization capabilities achieve sustained competitive advantages through superior decision-making quality, operational agility, and strategic alignment.

Future research directions warrant investigation of advanced analytics integration including machine learning and artificial intelligence, privacy-preserving analytics architectures, and federated learning approaches enabling distributed analysis. These capabilities will enable next-generation intelligence systems providing prescriptive guidance and enabling autonomous decision-making support. This research provides practitioners with frameworks, design principles, and implementation guidance supporting effective business intelligence system deployments and sustained organizational advantage.

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KORPORATİV MƏLUMAT BAZALARININ BULUD İNFRASTRUKTURUNA MİQRASIYASI ZAMANI İNFORMASIYA TƏHLÜKƏSİZLİYİNİN İDARƏ EDİLMƏSİ MEXANİZMLƏRİ

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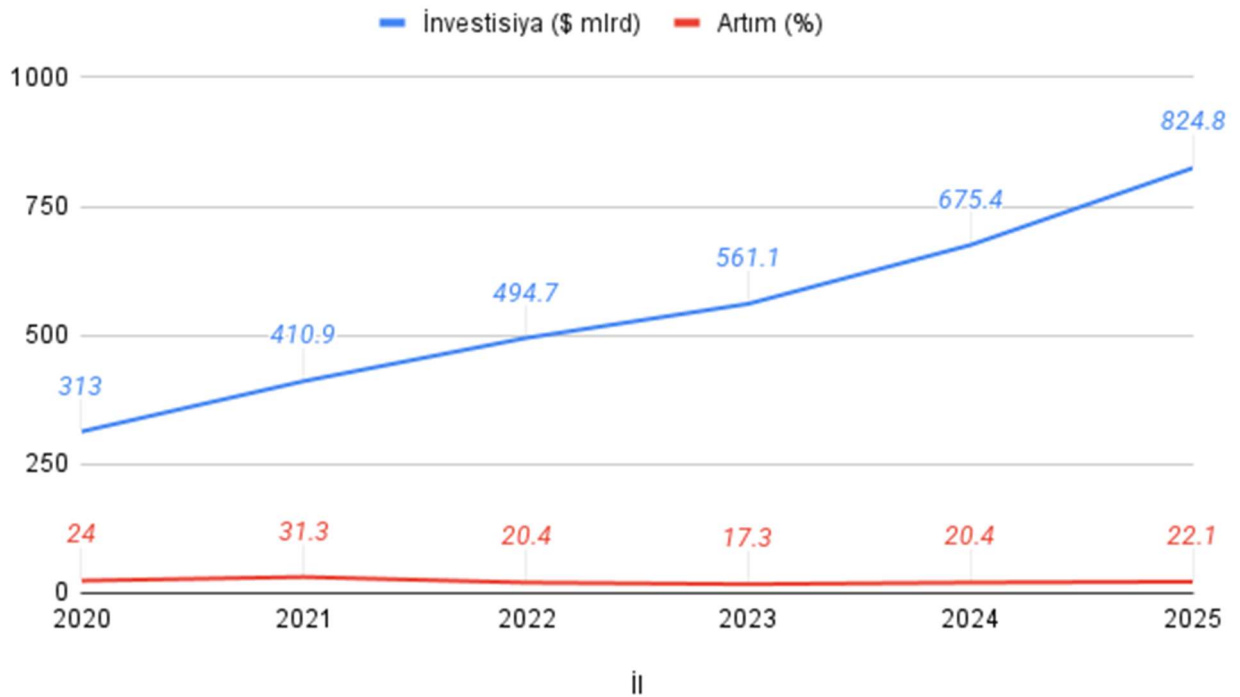
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Bugünkü sürətlənmiş rəqəmsal transformasiya dövründə müəssisə verilənlər bazalarının ənənəvi yerli server mühitlərindən bulud infrastrukturuna köçürülməsi bank və maliyyə sənayesi üçün qaçılmaz strateji seçimə çevrilmişdir. Lakin, bu proses iqtisadi fayda gətirməklə yanaşı, mürəkkəb və çoxşaxəli təhlükəsizlik riskləri də yaradır. Bu tədqiqat bu riskləri idarə etmək üçün hazırlanmış qabaqcıl mexanizmləri sistematik şəkildə araşdırmağı hədəfləyir. Tədqiqatda tənzimləyici sənədlərin və mövcud elmi ədəbiyyatın nəzərdən keçirilməsi ilə birlikdə sistematik müqayisəli təhlil yanaşması tətbiq olunur. Burada perimetr təhlükəsizlik imkanlarının azaldılmasında Sıfır Etibar Memarlığının (ZTA) rolu, məlumat itkisinin qarşısının alınmasında (DLP) Bulud Giriş Təhlükəsizlik Brokerinin (CASB) effektivliyi, Şəxsiyyət və Giriş İdarəetmə (IAM) sistemlərindəki son tendensiyalar və parol qorunmasında homomorfik şifrələmənin tətbiq potensialı araşdırılır. Bundan əlavə, bu tədqiqatda ISO/IEC 27017 və NIST standartlarının müəssisə miqrasiyası proseslərində hüquqi və texniki tətbiqləri təhlil edilir. Nəticələr göstərir ki, bu texniki mexanizmlərin beynəlxalq standartlarla hədəflənmiş integrasiyası bulud infrastrukturunu ənənəvi yerli serverlərə nisbətən daha etibarlı, idarəolunan və davamlı bir platformaya çevirə bilər.

Açar sözlər: informasiya təhlükəsizliyi, Sıfır Etibar Arxitekturası (ZTA), Bulud Giriş Təhlükəsizliyi Brokeri (CASB), Şəxsiyyət və Giriş İdarəetməsi (IAM), homomorfik şifrələmə, müəssisə məlumat bazaları, ISO/IEC 27017, NIST.

1. Giriş: Korporativ Mühitdə Bulud Miqrasiyasının Qlobal Trendləri

Dördüncü Sənaye İnqilabının texnoloji irəliləyişləri qlobal rəqəmsallaşma dalğasına səbəb oldu və biznes dünyasının müxtəlif sektorlarını, xüsusən də bankları və maliyyə institutlarını mövcud IT infrastrukturlarını yenidən nəzərdən keçirməyə məcbur etdi. Bu transformasiya təkcə texnoloji yenilənmə deyil, həm də strateji bir zərurətdir və idarəetmə konsepsiyalarının əsaslı şəkildə yenidən qurulmasını tələb edir. Çoxsaylı beynəlxalq tədqiqatlar göstərir ki, 2025-ci ilin sonuna qədər böyük maliyyə institutlarının böyük əksəriyyəti əsas verilənlər bazalarını ənənəvi yerli server mühitlərindən mərkəzləşdirilmiş bulud infrastrukturuna köçürəcək. Maliyyə xidmətləri sənayesindəki proqnozlar göstərir ki, 2026-cı ildə bulud texnologiyasına ümumi investisiya 1 trilyon dollara yaxınlaşacaq və illik artım faizi 20%-i keçəcək. Aşağıda göstərilmiş şəkil 1-də isə 2020-2025-ci illər intervalındakı investisiya məbləği və artım faizi təsvir edilmişdir:



Şəkil 1: İnvestisiya məbləği və Artım faizi [1]

Bununla belə, verilənlər bazalarının bulud platformalarına miqrasiyasını yalnız xərc səmərəliliyi və texnoloji çeviklik baxımından qiymətləndirmək birtərəflidir. Bu proses həmçinin bir sıra mürəkkəb və çoxşaxəli informasiya təhlükəsizliyi risklərini də gətirir. Ənənəvi mülkiyyət sistemlərinin müasir bulud arxitekturalarına inteqrasiyası, miqrasiya prosesi zamanı məlumatların bütövlüyünün qorunması və beynəlxalq uyğunluq standartlarına uyğunluğun təmin edilməsi bu gün müəssisələrin üzləşdiyi ən çətin texniki problemlərdəndir [2]. Buluda keçidlə məlumatlar artıq birbaşa təşkilat tərəfindən idarə olunmur, üçüncü tərəf xidmət təminatçısının server infrastrukturunda yerləşdirilir. Bu fundamental dəyişiklik kiberhücumların coğrafi mənzərəsini də dəyişdirib: haker qrupları və kibercinayətkarlar artıq korporativ fiziki şəbəkələri, bulud API-lərini, səhv konfigurasiya edilmiş yaddaşı və istifadəçi etimadnaməsini hədəf alırlar. Bu fonda, bu tədqiqat müəssisə verilənlər bazasının miqrasiyası və sonradan bu yeni kibertəhdidlərin aradan qaldırılması üçün istifadə üçün tələb olunan çoxqatlı, yüksək səviyyəli informasiya təhlükəsizliyi mexanizmlərinin sistematik təhlilinə yönəlib.

2. Bulud Təhlükəsizliyində Müasir Arxitektura Yanaşmalar

Təhlükəsiz verilənlər bazası miqrasiyası sadəcə bir sıra texniki əməliyyatlardan ibarət deyil; bu, təhlükəsizliyin kökündən yenidən düşünülməsini tələb edir. Müəssisələr passiv, reaktiv təhlükəsizlik modellərindən imtina etməli və proaktiv, təhdidlərə qarşı həssas memarlıq yanaşmasını tətbiq etməlidirlər. Müasir bulud təhlükəsizliyinin konseptual təməli bir sıra texnoloji paradigmlər üzərində qurulub və bu paradigmlər bu perspektivdən qaynaqlanır.

2.1. Sıfır Etibar Arxitekturası (Zero Trust Architecture)

Ənənəvi müəssisə şəbəkəsi modelində daxili şəbəkəyə qoşulmuş istənilən cihaz və ya istifadəçi adətən etibarlı hesab olunur və əlavə yoxlama tələb etmir. Bu yanaşma qapalı fiziki sərhədlər dövründə çətinliklə saxlanıla bilsə də, bulud infrastrukturuna keçidlə onun tətbiqi əhəmiyyətli dərəcədə azalıb. Fiziki sərhədlərin yox olduğu yeni mühitdə "Sıfır Etibar" (Zero Trust) arxitekturası aparıcı alternativ model kimi çox diqqət çəkib və global miqyasda geniş şəkildə tanınıb. Rəqəmsal bank xidmətlərini və həssas korporativ verilənlər bazalarını qorumaq baxımından sıfır etibar paradigması ənənəvi perimetr təhlükəsizliyini tamamilə kənara qoyur və "heç vaxt etibar etmə, həmişə yoxla" anlayışını sistemin əsasına qoyur [3].

Bu arxitekturanın mahiyyəti ondan ibarətdir ki, istifadəçinin və ya cihazın şəbəkə daxilində və ya xaricində olmasının fərqi yoxdur; sistem resurslarına giriş tələb edən hər bir qurum davamlı çoxmərhələli yoxlamadan keçməlidir [4]. Məsələn, bir işçi korporativ intranet vasitəsilə miqrasiya olunmuş bank verilənlər bazasına daxil olsa belə, sistem cihazının texniki vəziyyətini, şəbəkə ünvanını və davranış xüsusiyyətlərini real vaxt rejimində təhlil edəcək. Bu davamlı monitoring həm daxili təhdidləri (insider threats) idarə edə, həm də şəbəkə daxilində sistemlər arasında sərbəst hərəkət etməyi hədəfləyən zərərli proqram (lateral movement) təminatının qarşısını ala bilər.

2.2. Bulud Giriş Təhlükəsizliyi Brokerləri (CASB)

Müasir informasiya təhlükəsizliyi sahəsində bulud əsaslı müəssisə verilənlər bazalarına təhlükəsiz uzaqdan giriş əsas prioritetə çevrilib. Bulud Giriş Təhlükəsizlik Brokeri (Cloud Access Security Broker, CASB) bu sahədə ən çox istifadə edilən və geniş tətbiq olunan texniki həllərdən biridir. CASB, müəssisə istifadəçiləri ilə bulud xidməti təminatçısının infrastrukturunu arasında aralıq idarəetmə təbəqəsi kimi çıxış edən, bütün məlumat mübadiləsini izləyən və müəyyən təhlükəsizlik siyasətlərini avtomatik olaraq tətbiq edən aparat və proqram təminatı həllidir [5].

Funksional arxitektura baxımından CASB sistemləri məlumat itkisinin qarşısının alınması (Data Loss Prevention, DLP) sistemlərinin əhatə dairəsindən kənara çıxır; bu platformalar həmçinin zərərli proqram aşkarlanması, adaptiv giriş nəzarəti və qeyri-adi istifadəçi davranışlarının təhlili (User Behavior Analytics, UBA) kimi digər təhlükəsizlik funksiyalarını vahid sistemə integrasiya edir. Bu integrasiya olunmuş platforma həmçinin sıfır-gün (zero-day) tipli hücumlarla effektiv şəkildə mübarizə apara bilər [6]. Məsələn, istifadəçi müəssisənin verilənlər bazasından həssas müştəri məlumatlarını, o cümlədən ödəniş kartı məlumatlarını yükləməyə və xarici şəbəkəyə ötürməyə cəhd edərsə, CASB sistemi əməliyyatı dərhal aşkarlayacaq və avtomatik olaraq bloklayacaq.

2.3. Şəxsiyyət və Girişin Dinamik İdarə Edilməsi (IAM)

Verilənlər bazalarının buluda köçürülməsi Şəxsiyyət və Giriş İdarəetməsi (Identity and Access Management, IAM) sistemlərinin əhatə dairəsini xeyli genişləndirmiş və bu platformaları sadə parol identifikasiyası mexanizmlərindən müasir müəssisə infrastrukturunun əsas təhlükəsizlik təbəqəsinə çevirmişdir. Müasir IAM həlləri “ən az imtiyaz” (least privilege) prinsipinə əsaslanır; yəni hər bir istifadəçiyə yalnız funksional tapşırıqlarını yerinə yetirmək üçün lazım olan giriş imtiyazları verilir.

2025-ci il Qlobal Müəssisə Təhlükəsizliyi Trendləri Hesabatı göstərir ki, getdikcə daha çox təşkilat ənənəvi parol əsaslı identifikasiyadan imtina edərək “Parolsuz Autentifikasiya” (Passwordless Authentication) modelləri və FIDO2 token texnologiyasına üstünlük verir. Bundan əlavə, müasir IAM platformaları artıq istifadəçi identifikasiyasının idarə edilməsi ilə məhdudlaşmır; bu həllər üçüncü tərəf tətbiqlərini, tətbiq interfeyslərini (API) və maşın identifikasiya kodlarını (machine identities) mərkəzləşdirilmiş idarəetmə sisteminə integrasiya edir ki, bu da global müəssisə infrastrukturunun qorunması üçün ən vacib mexanizmə çevrilmişdir [7].

2.4. Məlumatların Kriptografik Qorunması və Homomorfik Şifrələmə

Yerli serverlərdən bulud infrastrukturuna ötürülmə və saxlama zamanı məlumatların şifrələnməsi beynəlxalq təcrübədə geniş qəbul edilmiş bir standart halına gəlmişdir. Lakin, ənənəvi şifrələmə təhlükəsizlik həllərinin ən ciddi zəifliyi məlumatlar bulud serverlərində aktiv şəkildə emal edildikdə baş verir. Ənənəvi sistemlərdə bulud xidməti təminatçıları istənilən axtarış və ya hesablama aparmaq üçün məlumatları müvəqqəti olaraq deşifrə etməli, yəni açıq mətnə çevirməlidirlər. Bu, məlumatları müvəqqəti olaraq potensial hücumlara məruz qoyur.

Müasir müəssisə arxitekturaları bu texniki çətinliyin öhdəsindən gəlmək üçün “Homomorfik Şifrələmə” (Homomorphic Encryption) texnologiyasını tətbiq etməyə başlayıblar. Qabaqcıl riyazi metodlara əsaslanan bu texnologiya, bulud serverlərinə məlumatların deşifrəsini açmadan birbaşa şifrələnmiş mətn üzərində axtarışlar, aqreqasiyalar və statistik təhlillər aparmağa imkan verir. Bu xüsusiyyət texnologiyayı xüsusilə səhiyyə, maliyyə və dövlət idarəçiliyi kimi yüksək məxfilik tələb edən sahələr üçün perspektivli bir həll edir [8].

3. Bulud Təhlükəsizliyinin İdarə Edilməsində Beynəlxalq Standartlar

Texniki mexanizmlərin özbaşına və hissə-hissə tətbiqi yetərli deyil; miqrasiya prosesi özünün hüquqi və metodoloji əsasını hamı tərəfindən qəbul edilmiş global informasiya təhlükəsizliyi standartlarında tapmalıdır:

- **ISO/IEC 27017:2015 Çərçivəsi:** ISO/IEC 27017, dünyada ən çox istifadə edilən bulud mühiti standartı olan ISO 27001-in xüsusi bir genişləndirilməsidir və müəssisə verilənlər bazası miqrasiyası üçün xüsusi tələbləri müəyyən edir. Standart, vəzifələrin aydın şəkildə ayrılması, virtual mühitlər arasında təcrid və müqavilə münasibətlərinə xitam verildikdə müştəriyə məxsus aktivlərin (verilənlər bazaları da daxil olmaqla) təhlükəsiz şəkildə silinməsi daxil olmaqla, xüsusi bulud resurslarına nəzarət tədbirlərini əhatə edir [9].
- **NIST Təlimatları:** Milli Standartlar və Texnologiya İnstitutu (NIST) tərəfindən hazırlanmış SP 800-210 sənədi bulud mühitlərində giriş nəzarətinin əsas prinsiplərini müəyyən edir. Bu sənəd, giriş nəzarətinin IaaS, PaaS və SaaS xidmət modelləri boyunca təbəqələr şəklində tətbiq edilməli olduğunu və əsas modeldə müəyyən edilmiş idarəetmə mexanizmlərinin yuxarı təbəqə modelinə tətbiq edilməli olduğunu vurğulayır [10]. Bundan əlavə, NIST SP 800-144 müəssisələrə xatırladır ki, məlumatların saxlanması və emalı texniki olaraq bulud xidməti təminatçılara həvalə edilə bilsə də, müəssisələrin özləri həmişə bu məlumatlar üçün son hüquqi və etik məsuliyyət daşıyırlar [11].

4. Nəticə

Tədqiqat və təhlillər göstərir ki, müəssisə verilənlər bazalarının, xüsusən də maliyyə və bank sektorundakı verilənlər bazalarının bulud infrastrukturuna köçürülməsi müasir rəqəmsal iqtisadiyyatın obyektiv tələbləri ilə idarə olunan qaçılmaz bir tendensiyaadır. Lakin, bu transformasiya yalnız texniki səviyyə ilə məhdudlaşmır; o, həmçinin müəssisələrdən ənənəvi, statik informasiya təhlükəsizliyi metodlarından imtina etməyi və bunun əvəzinə dinamik, çoxqatlı və davamlı olaraq yenilənən mühafizə strategiyalarını tətbiq etməyi tələb edir.

Tədqiqat nəticələri göstərir ki, Sıfır Etibar (Zero Trust) əsaslı mikro segmentasiya, süni intellektlə idarə olunan Bulud Giriş Təhlükəsizlik Brokerləri (CASB) və homomorfik şifrələmə kimi qabaqcıl texnologiyalar, tam tətbiq olunarsa, məlumatların sızmasının qarşısını effektiv şəkildə ala bilər. Lakin, təkə texniki vasitələr kifayət deyil; uyğunluq və idarəetmə şəffaflığını təmin etmək üçün bu texnologiyalar ISO/IEC 27017 və NIST standartları ilə ardıcıl olaraq integrasiya olunmalıdır. Müəssisələr elmi cəhətdən təsdiqlənmiş bu standartlaşdırılmış çərçivələrə əsaslanaraq miqrasiya proseslərini planlaşdırdıqda və həyata keçirdikdə, bulud infrastrukturunu ənənəvi yerli server mühitlərindən daha etibarlı, çevik və idarə olunması daha asan olan bir texnologiyaya çevrilə bilər.

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MECHANISMS OF INFORMATION SECURITY MANAGEMENT DURING THE MIGRATION OF CORPORATE DATABASES TO CLOUD INFRASTRUCTURE

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Abstract

In today's accelerated digital transformation era, migrating enterprise databases from traditional on-premise server environments to cloud infrastructure has become an inevitable strategic choice for the banking and finance industry. However, while this process brings economic benefits, it also creates complex and multifaceted security risks. This study aims to systematically examine the advanced mechanisms designed to manage these risks. The study applies a systematic comparative analysis approach along with a review of regulatory documents and existing scientific literature. It examines the role of Zero Trust Architecture (ZTA) in reducing perimeter security vulnerabilities, the effectiveness of Cloud Access Security Broker (CASB) in data loss prevention (DLP), recent trends in Identity and Access Management (IAM) systems, and the potential for homomorphic encryption in password protection. In addition, this study analyzes the legal and technical applications of ISO/IEC 27017 and NIST standards in enterprise migration processes. The results show that targeted integration of these technical mechanisms with international standards can transform cloud infrastructure into a more reliable, manageable, and sustainable platform than traditional on-premises servers.

Keywords: information security, Zero Trust Architecture (ZTA), Cloud Access Security Broker (CASB), Identity and Access Management (IAM), homomorphic encryption, enterprise databases, ISO/IEC 27017, NIST.

МЕХАНИЗМЫ УПРАВЛЕНИЯ ИНФОРМАЦИОННОЙ БЕЗОПАСНОСТЬЮ ПРИ МИГРАЦИИ КОРПОРАТИВНЫХ БАЗ ДАННЫХ В ОБЛАЧНУЮ ИНФРАСТРУКТУРУ

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Резюме

В условиях ускоренной цифровой трансформации сегодня миграция корпоративных баз данных с традиционных локальных серверных сред на облачную инфраструктуру стала неизбежным стратегическим выбором для банковской и финансовой отрасли. Однако, хотя этот процесс приносит экономические выгоды, он также создает сложные и многогранные риски безопасности. Цель данного исследования — систематически изучить передовые механизмы, предназначенные для управления этими рисками. В исследовании применяется систематический сравнительный анализ, а также обзор нормативных документов и существующей научной литературы. Рассматривается роль архитектуры нулевого доверия (ZTA) в снижении уязвимостей периметровой безопасности, эффективность брокера безопасности доступа к облаку (CASB) в предотвращении потери данных (DLP), последние

тенденции в системах управления идентификацией и доступом (IAM) и потенциал гомоморфного шифрования в защите паролей. Кроме того, в этом исследовании анализируются правовые и технические аспекты применения стандартов ISO/IEC 27017 и NIST в процессах миграции корпоративных баз данных. Результаты показывают, что целенаправленная интеграция этих технических механизмов с международными стандартами может преобразовать облачную инфраструктуру в более надежную, управляемую и устойчивую платформу, чем традиционные локальные серверы.

Ключевые слова: информационная безопасность, архитектура нулевого доверия (ZTA), брокер безопасного доступа к облаку (CASB), управление идентификацией и доступом (IAM), гомоморфное шифрование, корпоративные базы данных, ISO/IEC 27017, NIST.

Embodied Vulnerability and Cognitive Load in Immersive Gameplay: A Comparative Study of Virtual Reality and Desktop 3D Environments

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Abstract

Virtual reality (VR) environments are frequently associated with heightened immersion and emotional intensity, particularly in contexts involving environmental threat, spatial uncertainty, and perceived vulnerability. While immersive systems are often assumed to amplify experiential engagement, less attention has been given to how such intensification relates to perceived cognitive workload. The present study investigates the intersection between embodied vulnerability, immersive tension, and cognitive demand in VR and desktop 3D gameplay.

Using a within-subject experimental design ($N = 30$), participants experienced both a VR game (*Astro Bot: Rescue Mission*) and a desktop 3D game (*Black Myth: Wukong*). After each session, participants completed the NASA Task Load Index (NASA-TLX) and selected subscales of the Game Experience Questionnaire (GEQ), including immersion and tension.

Results indicate that VR gameplay significantly increases perceived workload, immersion, and tension-related affect compared to desktop gameplay. A positive correlation between immersion and mental demand suggests that intensified experiential engagement is sustained through greater allocation of attentional resources.

The findings contribute to research on immersive media, experiential learning, and interactive environments by positioning cognitive load as a measurable component of immersive engagement. The study highlights the importance of balancing affective intensity and cognitive sustainability in the design of advanced interactive systems.

1. Introduction

Immersive technologies are transforming interactive digital environments across entertainment, education, and training domains. Virtual reality (VR), in particular, offers sensorimotor integration, stereoscopic depth perception, and spatialized interaction that differentiate it fundamentally from traditional desktop-based interfaces. These affordances increase spatial presence and perceptual immediacy, potentially intensifying user engagement.

In interactive systems, immersion is often described as a multidimensional construct encompassing perceptual absorption, emotional involvement, and attentional focus. Previous research has shown that VR environments can enhance presence and emotional response compared to non-immersive platforms (Slater 2018; Pallavicini et al. 2020). However, increased immersion may not be cognitively neutral.

Cognitive Load Theory (Sweller 1988) suggests that human working memory resources are limited. Tasks requiring spatial coordination, continuous monitoring, and rapid decision-making may elevate perceived mental effort. Studies in immersive learning contexts have shown that VR environments can increase both presence and cognitive load simultaneously (Makransky et al. 2019; Makransky and Petersen 2021).

In game environments, especially those involving threat, tension, or high environmental complexity, immersive features may intensify vigilance and attentional allocation. VR may heighten embodied interaction, requiring additional spatial orientation and sensorimotor integration compared to desktop interfaces.

Despite growing interest in immersive systems, limited empirical research directly compares perceived workload and player experience between VR and desktop gameplay within a controlled design. The present study addresses this gap by examining both experiential and cognitive dimensions of gameplay across platforms.

2. Theoretical Background

2.1 Immersion and Presence

Presence refers to the subjective sensation of “being there” within a mediated environment. High levels of presence have been linked to emotional intensity and behavioral engagement. VR systems enhance presence through head-tracking, wide field-of-view displays, and interactive spatial alignment.

However, presence is not solely affective; it involves sustained attentional commitment. The more cognitively involved a user becomes in maintaining spatial awareness and environmental monitoring, the greater the potential cognitive cost.

2.2 Cognitive Load in Immersive Systems

Cognitive load can be divided into intrinsic, extraneous, and germane load. VR environments may increase extraneous load due to interface novelty, sensorimotor demands, or perceptual complexity. At the same time, immersive environments may enhance germane load by supporting deeper engagement.

Understanding how these forms of load interact with experiential immersion remains a critical research question.

2.3 Embodied Interaction

Embodied interaction theory suggests that cognition is shaped by bodily engagement with the environment. In VR gameplay, the player's head and body movements directly influence perception and interaction. This may intensify both engagement and attentional demand.

3. Research Questions and Hypotheses

RQ1: Does VR gameplay produce higher perceived cognitive workload than desktop gameplay?

RQ2: Does VR gameplay enhance immersion and tension-related experience?

RQ3: Is immersion positively associated with perceived mental demand?

H1: VR will result in higher NASA-TLX scores.

H2: VR will produce higher immersion and tension scores.

H3: Immersion will positively correlate with mental demand.

4. Methodology

4.1 Design

A within-subject experimental design was used. All participants completed both conditions and order was counterbalanced.

4.2 Participants

Thirty participants (N = 30; 18 male, 12 female; mean age = 23.4 years) were recruited from a university population. All participants reported prior gaming experience. Participants provided informed consent.

4.3 Materials

VR condition: *Astro Bot: Rescue Mission* (Sony Interactive Entertainment, 2018).

Desktop condition: *Black Myth: Wukong* (Game Science, 2024).

Hardware included a PlayStation VR headset and a high-performance gaming PC with a 24-inch monitor.

4.4 Measures

NASA-TLX measured perceived workload (mental demand, physical demand, temporal demand, effort, frustration, performance).

The Game Experience Questionnaire measured immersion and tension using a 5-point Likert scale.

4.5 Procedure

Participants completed a 20-minute gameplay session in each condition. After each session, questionnaires were administered. A 10-minute rest interval separated conditions.

4.6 Statistical Analysis

Data were analyzed using paired-samples t-tests and Pearson correlations. Effect sizes (Cohen's d) were calculated.

5. Results

VR gameplay resulted in significantly higher overall NASA-TLX scores ($M = 62.40$, $SD = 8.70$) compared to desktop gameplay ($M = 48.90$, $SD = 7.90$), $t(29) = 5.12$, $p < .001$, $d = 0.93$.

Immersion scores were significantly higher in VR ($M = 4.30$, $SD = 0.60$) than desktop ($M = 3.60$, $SD = 0.70$), $t(29) = 4.45$, $p < .001$, $d = 0.81$.

Tension scores were also elevated in VR, $t(29) = 3.02$, $p = .005$.

A significant positive correlation was observed between immersion and mental demand in the VR condition ($r = .54$, $p = .002$).

6. Discussion

The findings indicate that VR intensifies both experiential engagement and perceived cognitive workload. The large effect size observed for workload suggests substantial attentional involvement in immersive gameplay.

Increased immersion appears cognitively supported rather than cognitively effortless. The positive correlation between immersion and mental demand suggests that sustained engagement may require greater attentional allocation.

From a design perspective, immersive systems should balance experiential intensity with cognitive sustainability. Overload may reduce user comfort or performance, particularly in extended sessions

7. Implications for Modern Learning and Immersive System Design

The present findings have implications that extend beyond entertainment-oriented game research and into the broader domain of immersive learning and interactive system design. Virtual reality is increasingly adopted in education, professional training, medical simulation, military preparation, and technical skill acquisition. In such contexts, immersive engagement is often regarded as inherently beneficial. However, the results of this study suggest that increased immersion may be accompanied by elevated cognitive workload, which must be carefully managed.

From a cognitive perspective, immersive VR systems may simultaneously enhance motivation and impose additional mental demands. Increased spatial presence, sensorimotor integration, and environmental realism can deepen engagement, yet these features may also increase extraneous cognitive load if not properly structured. For example, excessive environmental complexity or poorly guided interaction may overload working memory resources, reducing learning efficiency. The positive association observed between immersion and mental demand in the VR condition suggests that immersive intensity is cognitively sustained. This has direct implications for instructional design. In learning environments, designers should aim to optimize germane cognitive load (i.e., effort directed toward meaningful processing) while minimizing unnecessary extraneous load. Structured guidance, progressive difficulty scaling, and adaptive feedback systems may help balance engagement and cognitive sustainability.

Furthermore, embodied interaction in VR may influence how learners encode spatial and procedural information. When users physically orient, look around, and interact with objects in

three-dimensional space, memory formation may be strengthened through multisensory integration. However, if cognitive resources are overly consumed by environmental navigation, less capacity may remain for conceptual integration.

These findings suggest that immersive learning environments should incorporate workload assessment as part of evaluation protocols. Instruments such as NASA-TLX may provide valuable insight into how users perceive mental demand in VR-based training modules. By systematically measuring workload, designers can identify potential overload conditions before implementation in high-stakes contexts.

In addition, adaptive VR systems may benefit from real-time monitoring mechanisms capable of adjusting environmental intensity or task complexity based on user performance. Balancing immersion and cognitive demand may improve both user satisfaction and knowledge retention.

Thus, rather than conceptualizing immersion as an unqualified advantage, immersive design should be understood as a dynamic interplay between experiential intensity and attentional capacity. Effective VR systems are not those that maximize immersion indiscriminately, but those that calibrate experiential richness to cognitive limits.

8. Conclusion

This study examined the relationship between immersive engagement and perceived cognitive workload in virtual reality and desktop 3D gameplay. The findings demonstrate that VR significantly increases immersion, tension-related affect, and overall perceived mental demand compared to desktop gameplay. Moreover, the positive correlation between immersion and mental demand suggests that experiential intensity in immersive systems is cognitively supported rather than effortless.

These results contribute to contemporary discussions on immersive technologies by highlighting the dual nature of VR engagement. While immersive environments enhance emotional involvement and attentional focus, they also require greater allocation of cognitive resources. Immersion, therefore, should not be viewed solely as an affective construct but as a cognitively embedded process.

Importantly, the findings suggest that embodied interaction intensifies not only perceptual realism but also attentional vigilance. Users in VR must continuously process spatial orientation, environmental cues, and interaction feedback. This sustained monitoring may elevate perceived workload, even in non-horror gameplay contexts.

The study also provides methodological value by integrating experiential and workload measures within a single experimental framework. Combining NASA-TLX with GEQ enables a more comprehensive understanding of immersive systems, capturing both affective and cognitive dimensions of user experience.

Several limitations should be acknowledged. The sample size was moderate, and participants were primarily experienced gamers. Additionally, the games selected, while immersive, were not exclusively designed as horror titles. Future research may examine genre-specific VR horror environments, incorporate physiological indicators of arousal, and apply longitudinal designs to investigate adaptation effects.

In conclusion, immersive VR systems amplify experiential engagement while increasing cognitive demand. Designers of interactive entertainment, training simulations, and educational platforms should recognize that heightened immersion entails measurable cognitive costs. Effective immersive design requires careful calibration between emotional intensity and cognitive sustainability.

By integrating cognitive load theory with immersive interaction research, this study contributes to a more nuanced understanding of modern interactive systems. As VR technologies continue to evolve, empirical examination of the balance between engagement and workload will remain essential for optimizing both user experience and functional effectiveness.

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Развитие научных основ совершенствования процесса электроразогрева бетонной смеси в технологии зимнего бетонирования

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Аннотация

Зимнее бетонирование остается одной из наиболее технологически чувствительных операций монолитного строительства, поскольку низкая температура одновременно замедляет гидратацию цемента, увеличивает риск раннего замораживания свободной воды и усложняет управление прочностным развитием конструкции. Электроразогрев бетонной смеси в этих условиях не должен рассматриваться только как способ «подать тепло» в материал. Его научная сущность связана с управлением тепломассопереносом, электрическим сопротивлением цементной системы, кинетикой гидратации, градиентами температурного поля и моментом достижения критической прочности. Цель статьи - сформировать научно обоснованную модель совершенствования электроразогрева бетонной смеси для технологии зимнего бетонирования с учетом нормативных требований, исследований по электропрогреву, метода зрелости и современных решений на основе проводящих цементных композитов. В результате предложена адаптивная трехконтурная схема электроразогрева: тепловой контур стабилизирует температуру, электрический контур контролирует сопротивление и мощность, прочностной контур связывает температурную историю с прогнозом набора прочности. Практическая значимость заключается в снижении риска перегрева, локального недогрева, избыточного энергопотребления и преждевременного снятия тепловой защиты.

Ключевые слова: зимнее бетонирование, электроразогрев бетонной смеси, электропрогрев, температурное поле, гидратация цемента, метод зрелости, критическая прочность, греющий провод, проводящий бетон, тепловой режим

Введение

Зимнее бетонирование становится проблемой не тогда, когда температура воздуха опускается ниже нуля, а раньше - в момент, когда строительная площадка теряет возможность опираться на естественный тепловой ресурс цементной гидратации. В нормальных условиях цементный камень сам создает часть тепла, необходимого для начального структурообразования, но при охлаждении скорость химических реакций падает, вода в капиллярной системе становится фактором риска, а прочность перестает нарастать с тем темпом, который нужен для распалубки, нагружения и сохранения долговечности. ACI 306R-16 прямо связывает защиту свежееуложенного бетона с

достижением не менее 500 psi, то есть 3,5 МПа, поскольку бетон, защищенный от замерзания до этого уровня прочности, не повреждается от одного цикла замораживания в условиях отсутствия внешнего поступления воды [1].

В инженерной практике это означает, что электроразогрев не может быть рассчитан только по мощности трансформатора или длине нагревательного провода. Его необходимо связывать с фактической температурной историей смеси. ASTM C1074 устанавливает метод оценки прочности бетона через зрелость, где используется либо температурно-временной фактор, либо эквивалентный возраст при заданной температуре, а для конкретной смеси предварительно строится зависимость «прочность - зрелость» [2]. Такая логика особенно важна для зимнего бетонирования: одна и та же средняя температура воздуха не дает одинакового результата для массивной плиты, тонкой стены, колонны, ростверка или балки, потому что геометрия, теплоизоляция, влажность, цементный состав и схема подвода энергии меняют реальную температуру внутри бетона.

Научная проблема электроразогрева бетонной смеси состоит в том, что бетон в раннем возрасте является не пассивным телом, а изменяющейся электрохимической и теплофизической системой. Его электропроводность зависит от водоцементного отношения, ионного состава поровой жидкости, температуры, степени гидратации, содержания минеральных добавок и влажностного режима. В начале процесса смесь проводит ток иначе, чем через несколько часов, когда часть воды связывается в гидратных новообразованиях, а поровая структура начинает уплотняться. Поэтому фиксированный режим нагрева, удобный для монтажника, не всегда безопасен для материала. Слишком слабый режим оставляет конструкцию в зоне риска раннего замораживания. Слишком интенсивный режим ускоряет испарение влаги, усиливает температурные перепады и может ухудшать будущую структуру цементного камня.

Фундаментальная задача технологии состоит в согласовании трех процессов: выделения джоулева тепла, выделения тепла гидратации и отвода тепла через опалубку, утеплитель, арматуру и окружающий воздух. Если эти процессы не увязаны, электропрогрев превращается в эмпирическую операцию. Если увязаны - появляется управляемый технологический режим, где мощность нагрева корректируется не «по привычке», а по температуре бетона, изменению электрического сопротивления, расчетной зрелости и прогнозу достижения критической прочности.

Литературный обзор

Классическая школа бетоноведения, представленная работами P. Kumar Mehta и Paulo J. M. Monteiro, рассматривает свойства бетона через связь микроструктуры, состава и эксплуатационного поведения материала; в этой логике температура раннего твердения влияет не только на скорость набора прочности, но и на морфологию гидратных фаз, пористость, межфазную переходную зону и последующую долговечность цементного камня [3]. A. M. Neville, развивая физико-химическое понимание бетона, отдельно выделяет температурные эффекты, замораживание-оттаивание, прочность, усадку, ползучесть и долговечность как взаимосвязанные свойства, которые нельзя оценивать изолированно от режима выдерживания [4]. Для зимнего бетонирования это принципиально: кратковременное ускорение твердения не должно покупаться ценой скрытого дефекта структуры. В отличие от чисто технологического подхода, где главным считается достижение ранней распалубочной прочности, современное материаловедение требует учитывать позднюю прочность, трещиностойкость, водопоглощение и равномерность температурного поля.

Экспериментальные работы по электрическому воздействию на свежий бетон уточняют эту позицию. M. I. Batyuk, A. I. Gnyrya, V. Ya. Ushakov и S. V. Korobkov исследовали быстрый прямой электрический нагрев свежего бетона и показали, что объемный характер

прямого электрического нагрева способен создавать более равномерное температурное поле по сравнению с рядом поверхностных способов, но именно температурный градиент остается ограничивающим фактором при интенсификации режима [5]. Tayfun Uygunoğlu и İsmail Nosaoglu связали электрическое твердение с изменением сроков схватывания при разной интенсивности электрического воздействия; их работа важна тем, что переводит электропрогрев из области строительной «практики» в область управляемого влияния на раннюю структуру цементной системы [6].

Другая исследовательская линия связана с температурными полями в реальных зимних условиях. Tuo Shi, Chunlin Deng, Jiaqi Zhao, Pingxiang Ding и Zhihong Fan исследовали бетон, выдерживаемый при $-10\text{ }^{\circ}\text{C}$, с применением минеральной ваты, нагреваемой стальной опалубки и встроенной электрической нагревательной ленты; по результатам работы было показано, что комбинация теплоизоляции и нагреваемой опалубки может обеспечить требуемое качество зимнего твердения, а конечно-элементная модель пригодна для прогнозирования температурного поля конструкции [7]. Stepan Leontev и Andrey Taleyko предложили систему управления параметрами электрического выдерживания монолитных железобетонных конструкций, где учитываются температура бетона, температура наружного воздуха, время выдерживания и напряжение трансформатора; такая постановка особенно ценна, поскольку выводит электропрогрев на уровень автоматизированного управления, а не ручной корректировки [8].

Российские исследования по численному моделированию подтверждают, что расчет температурного поля становится обязательной частью зимней технологии. М. О. Dudin, N. I. Vatin и Yu. G. Barabanshchikov выполнили моделирование набора прочности бетона при прогреве монолитных конструкций проводом в ELCUT и WinConcret; сама постановка задачи показывает, что длина провода, шаг укладки, тепловая защита и прогноз прочности должны проектироваться вместе, а не выбираться раздельно [9]. Aleksei Gnyrya, Sergey Korobkov и Ivan Gaag на примере плитного фундамента показали, что численное решение тепловой задачи позволяет подбирать шаг намотки нагревательного провода на арматурный каркас, оценивать распределение температур и корректировать технологические мероприятия до выполнения работ на площадке [10].

Современный этап развития темы связан с проводящими цементными композитами. L. Zhang и соавторы исследовали углеродно-волокнуемый проводящий бетон, где электрическое сопротивление и температура твердения зависят от водосвязующего отношения, содержания крупного заполнителя и объема углеродного волокна; в эксперименте рассматривалось омическое выдерживание при $-20\text{ }^{\circ}\text{C}$ [11]. Emriye Çınar Resuloğulları, Tayfun Uygunoğlu, Barış Şimşek и İlker Bekir Topçu изучали влияние сажи на электрическое твердение свежего бетона для холодных регионов, что важно для перехода от внешнего нагревателя к материалу с регулируемой проводимостью [12]. Yinpeng He, Mengxi Zhang, Wenwei Li, Mingchao Li, Sijia Zhang, Genhua Deng и Xinyue Wang исследовали режимы электрического твердения температурно саморегулируемого бетона с наноглеродной сажей, включая режим постоянного напряжения и режим возрастающего напряжения [13]. Genhua Deng, Mengxi Zhang, Jinrui Zhang, Yinpeng He и Mingchao Li развили тему активного температурного управления саморегулируемым бетоном, связывая электрофизические свойства смеси с задачей ограничения температурных деформаций [14].

Наиболее свежие работы делают акцент на сочетании низкоуглеродных цементных систем и тепловой активации. Anna Antonova, Ekaterina Illarionova и Jouni Punkki исследовали бетон с 45 % и 70 % шлака в вяжущем и внутренний электрический кабельный нагрев; в условиях 20-30 Вт в течение первых 10-15 часов, что соответствовало 11,1-16,7 кВт·ч/м³, ранняя прочность бетона с 45 % и 70 % шлака повысилась до 14 % и 60 % соответственно в первые 24 часа без потери прочности в поздние сроки [15]. Данное обстоятельство

выступает основанием для осторожного, но перспективного вывода: электроразогрев может быть не только зимней аварийной мерой, а инструментом согласования низкоуглеродного состава бетона с требованиями ранней технологической прочности. L. A. Barna, P. M. Seman и C. J. Korhonen еще раньше сформулировали энергоэффективный подход к холодному бетонированию, где традиционная стратегия искусственного нагрева материалов и окружающей среды противопоставляется системам, сокращающим потребность во внешней энергии [16].

Материалы и методы

Методическая схема статьи построена на инженерно-научном синтезе нормативных требований и технологических зависимостей. В качестве объекта рассматривается бетонная смесь, укладываемая в условиях зимнего бетонирования и подвергаемая электротермическому воздействию до достижения критической или заданной технологической прочности. Предметом анализа являются тепловой режим, электрический режим и прочностная зрелость смеси в первые часы и сутки после укладки.

В нормативной части учитывалась логика СП 435.1325800.2018, где методы зимнего бетонирования должны приниматься с учетом типа конструкции, технологии бетонирования, состава смеси и климатических условий, а применяемые методы обязаны обеспечивать достижение бетоном критической прочности к требуемому сроку [17]. В технологической части использовались положения СП 70.13330.2012 о контроле температуры при прогреве: при электропрогреве температура должна контролироваться в первые 3 часа каждый час, а затем через 2 часа; это требование фактически задает минимальную частоту наблюдения за процессом, но не заменяет автоматизированного управления режимом [18].

Для построения научной модели применены четыре группы методов. Первая группа - физико-химический анализ ранней гидратации цемента, где температура рассматривается как фактор скорости реакции и формирования структуры. Вторая группа - теплотехнический расчет, включающий баланс подводимой электрической энергии, тепла гидратации и теплопотерь через ограждающие поверхности. Третья группа - электротехнический анализ, в котором бетонная смесь описывается как активное сопротивление с изменяющимися параметрами. Четвертая группа - прочностная интерпретация по зрелости, связывающая температурную историю конструкции с прогнозом набора прочности.

В технологическом отношении предложенная модель исходит из того, что электроразогрев должен выполняться не как одноразовое повышение температуры смеси, а как управляемая траектория. В этой траектории выделяются четыре фазы: предварительное доведение смеси до безопасного температурного уровня, мягкий начальный прогрев после укладки, стабилизация температуры в зоне активной гидратации, контролируемое охлаждение перед снятием тепловой защиты. Такая фазность снижает вероятность резких перепадов температуры между ядром и поверхностью конструкции, что особенно важно для массивных элементов, угловых участков, зон с густым армированием и конструкций с неодинаковой толщиной. Таблица 1 фиксирует методическую матрицу анализа.

Таблица 1 - Матрица параметров научно управляемого электроразогрева бетонной смеси

Блок контроля	Измеряемый или расчетный параметр	Научный смысл параметра	Технологическое решение
Температурный блок	Температура смеси при выпуске, доставке, укладке и выдерживании	Показывает фактическую тепловую историю бетона, а не только температуру воздуха	Корректировка мощности нагрева и толщины утепления
Электрический блок	Напряжение, ток, сопротивление, удельная мощность	Позволяет оценить устойчивость электрического контакта и изменение проводимости смеси	Выбор ступени трансформатора, шага электродов или нагревательного провода
Материаловедческий блок	Водоцементное отношение, тип цемента, добавки, минеральные компоненты	Определяет скорость гидратации, поровую структуру и чувствительность к охлаждению	Подбор состава смеси под зимний режим, а не только под класс прочности
Прочностной блок	Зрелость, критическая прочность, распалубочная прочность	Связывает температуру и время с реальным набором прочности	Решение о завершении прогрева, снятии опалубки и дальнейшем выдерживании
Рисковый блок	Температурный градиент, локальный перегрев, недогрев углов и кромок	Выявляет зоны, где возможно трещинообразование или раннее замораживание	Установка дополнительных датчиков, локальная теплоизоляция, изменение схемы нагрева

Данная матрица показывает, что электропрогрев нельзя сводить к электрической схеме. Бетонная смесь изменяет свойства в процессе твердения: часть воды вступает в реакцию, ионный состав порового раствора меняется, сопротивление растет или перераспределяется, а локальные участки с иной влажностью начинают греться не так, как расчетный «средний» объем. Следовательно, формируется предпосылка для перехода от нормативно допустимого, но эмпирического прогрева к режиму с обратной связью.

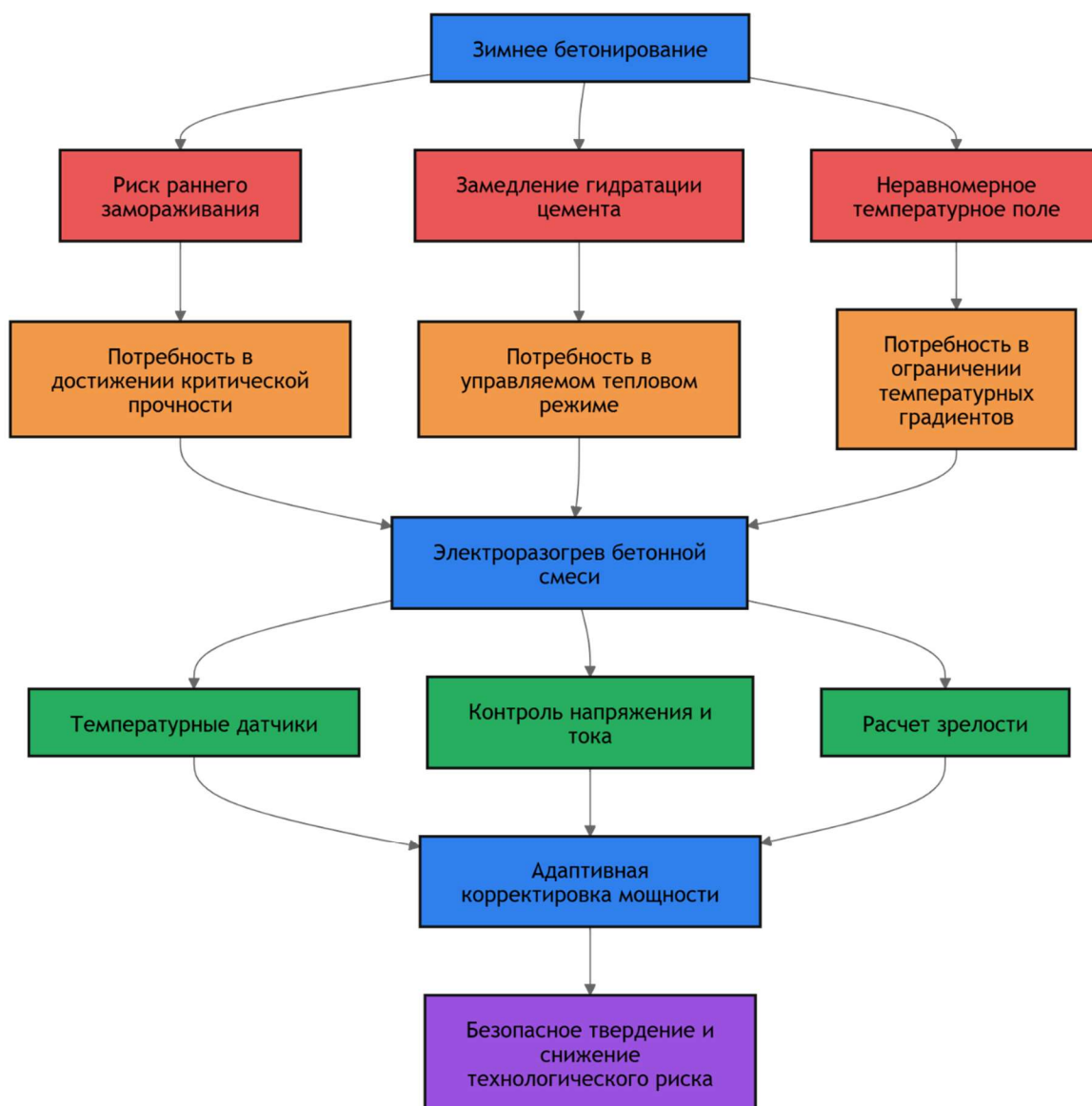


Рисунок 1 - Причинно-технологическая логика электропрогрева бетонной смеси

Представленная схема важна тем, что она меняет саму инженерную философию зимнего бетонирования. На площадке часто стремятся «не дать бетону замерзнуть», но такая формула слишком груба для современной технологии. Материал необходимо провести через ранний возраст так, чтобы гидратация не остановилась, вода не образовала разрушительную ледяную фазу, температура не ушла в опасные перепады, а энергия расходовалась на структурообразование, а не на бессистемный обогрев воздуха, опалубки и окружающего пространства.

Результаты

Первый результат состоит в уточнении научного статуса электропрогрева. Электропрогрев бетонной смеси является не вспомогательной операцией, а комбинированным теплоэлектрохимическим процессом, в котором электрическая энергия преобразуется в тепло внутри или около бетонного объема, а полученное температурное поле влияет на кинетику гидратации и формирование прочности. Чем раньше этот процесс начинает контролироваться по датчикам, тем меньше вероятность, что строитель получит внешне твердый, но внутренне неоднородный бетон.

Таблица 2 показывает различие основных методов зимнего бетонирования с позиции управляемости, рисков и области рационального применения. В таблице не приведены универсальные «лучшие» режимы, потому что универсального режима для всех конструкций не существует. Для тонкой стены, массивного ростверка, железобетонной колонны, фундаментной плиты и сборного элемента решающими будут разные сочетания геометрии, теплоизоляции, мощности и состава смеси.

Таблица 2 - Сравнение методов зимнего бетонирования по управляемости теплового режима

Метод	Механизм действия	Сильная сторона	Основное ограничение	Рациональная область применения
Метод термоса	Сохранение собственного тепла гидратации за счет теплоизоляции	Низкая энергоемкость, простота организации	Недостаточен при малой массивности и сильном охлаждении	Массивные конструкции с достаточным тепловыделением цемента
Противоморозные добавки	Снижение температуры замерзания жидкой фазы и ускорение твердения	Позволяют работать при пониженной температуре без интенсивного внешнего нагрева	Требуют строгого подбора под цемент, арматуру и условия эксплуатации	Конструкции, где допустимо химическое регулирование твердения
Электродный прогрев	Бетонная смесь включается в электрическую цепь как сопротивление	Быстрый объемный нагрев, высокая интенсивность	Риск неравномерности при изменении сопротивления и влажности	Стены, массивы, элементы с возможностью безопасного размещения электродов
Греющий провод	Тепло выделяется в проводнике и передается бетону контактно	Удобство укладки, применимость в плитах и фундаментах	Требует расчетного шага, защиты провода и контроля перегрева	Плиты, ростверки, фундаменты, протяженные элементы
Нагреваемая опалубка	Тепло подается через формообразующую поверхность	Хороший контроль поверхности, снижение риска промерзания кромок	Меньшая эффективность в массивном ядре без расчета теплопереноса	Балки, стенки, оболочки, мостовые элементы
Проводящий бетон	Тепло формируется за счет проводящей структуры цементного композита	Перспектива равномерного объемного нагрева и саморегулирования	Высокие требования к составу, дисперсности и стабильности проводящей фазы	Специальные конструкции, интеллектуальные материалы, низкотемпературные регионы

Сравнение показывает, что совершенствование электроразогрева должно идти не по пути механического увеличения мощности, а по пути повышения селективности теплового

воздействия. Слабое место традиционной технологии - разрыв между расчетом электрической схемы и фактическим поведением бетона. В проекте часто задается способ прогрева, но не всегда строится карта температурных рисков. Между тем именно карта показывает, где появится холодная зона, где возможен перегрев, какой участок будет охлаждаться быстрее после отключения питания и где следует разместить датчик.

Второй результат - разработка адаптивной трехконтурной модели управления. Ее смысл состоит в том, что один контур не способен обеспечить качество. Температура сама по себе не показывает прочность. Электрический ток сам по себе не показывает равномерность гидратации. Зрелость без измеренной температурной истории превращается в расчетную условность. Поэтому три контура должны работать одновременно.

Таблица 3 - Трехконтурная модель совершенствования электроразогрева бетонной смеси

Контур управления	Входные данные	Управляющее воздействие	Контролируемый риск	Ожидаемый технологический эффект
Тепловой контур	Температура смеси, температура ядра и поверхности, температура наружного воздуха	Изменение мощности, усиление или ослабление утепления, корректировка длительности выдерживания	Раннее замораживание, перегрев, резкое охлаждение	Более равномерное твердение и снижение риска трещинообразования
Электрический контур	Напряжение, сила тока, сопротивление, стабильность контактов	Переключение ступени трансформатора, изменение схемы подключения, проверка проводников	Локальный перегрев, обрыв цепи, неравномерное выделение тепла	Повышение надежности и энергоуправляемости процесса
Прочностной контур	Температурная история, расчет зрелости, контрольные испытания	Решение о продолжении или завершении прогрева, снятии защиты, распалубке	Преждевременное прекращение прогрева, недобор прочности	Обоснованное управление сроками и безопасностью работ

На этой основе можно сделать вывод о том, что главная научная новизна предлагаемого подхода заключается не в самой идее электрического нагрева, которая давно известна строительной практике, а в объединении теплового, электрического и прочностного контуров в единую систему принятия решений. Такой подход позволяет проектировать не «режим прогрева», а траекторию твердения. Разница существенная: режим прогрева отвечает на вопрос, сколько подать энергии; траектория твердения

отвечает на вопрос, какое состояние бетона должно быть достигнуто к конкретному моменту и каким способом это проверяется.

Третий результат связан с классификацией дефектов управления. В практике зимнего бетонирования дефект обычно обнаруживается поздно - при недоборе прочности, трещинах, нарушении сроков распалубки или споре между лабораторией и производством. Научно корректнее переводить дефекты в ранние диагностические признаки. Если температура ядра растет слишком быстро, а поверхность остается холодной, возникает градиент. Если ток резко падает или растет без объяснимой причины, меняется электрическое сопротивление системы. Если зрелость растет медленнее расчетной, конструкция еще не готова к снятию защиты даже при визуальной «схватившейся» поверхности.

Таблица 4 - Диагностические признаки технологических отклонений при электронагреве

Наблюдаемое отклонение	Вероятная причина	Материаловедческое последствие	Инженерное действие
Быстрый рост температуры в одной зоне	Слишком плотное расположение электродов или провода, локальная концентрация тока	Ускоренное высыхание, неравномерная гидратация, риск термического напряжения	Снижение ступени напряжения, проверка схемы подключения, перераспределение теплоизоляции
Низкая температура кромок и углов	Высокие теплотери через поверхность и опалубку	Риск локального замораживания и слабой зоны в защитном слое	Дополнительное утепление, перенос датчика к критической зоне, продление выдерживания
Рост сопротивления быстрее расчетного	Потеря влаги, изменение поровой структуры, нарушение контакта	Снижение эффективности объемного нагрева	Проверка контактов, корректировка мощности, контроль влажностного режима
Высокая температура при низкой расчетной зрелости	Кратковременный перегрев без достаточного времени выдерживания	Иллюзия технологической готовности без достаточного прочностного развития	Продолжение выдерживания по температурной истории, контрольные испытания
Резкое охлаждение после отключения	Недостаточная теплоизоляция или преждевременное снятие защиты	Температурное напряжение, риск микротрещин	Плавное снижение мощности, сохранение укрытия, контроль градиента

Такой диагностический подход делает зимнее бетонирование более прозрачным. Он позволяет не ждать конечного дефекта, а видеть его предпосылку. Особенно значимым становится размещение датчиков: один датчик в середине конструкции не способен представить реальную картину. Для массивных элементов необходимы точки в ядре, у поверхности, в угловых зонах и рядом с участками интенсивного теплового отвода. Для тонких стен важнее контроль поверхности, кромок и участков около опалубки. Для плит и

фундаментов существенны зоны около арматуры, греющих проводов и холодного основания.

Четвертый результат касается научной разработки режима электроразогрева. Предложенная модель включает не одну, а четыре фазы, каждая из которых имеет свое назначение. Смешение этих фаз является типичной причиной технологических ошибок. Например, если режим начального разогрева сразу переводится в режим высокой мощности, бетон может получить неравномерный температурный импульс. Если стабилизация не отделяется от охлаждения, защита снимается по календарю, а не по состоянию материала.

Таблица 5 - Фазная модель рационального электроразогрева бетонной смеси

Фаза	Цель	Управляемые параметры	Критерий перехода к следующей фазе	Технологический смысл
Подготовительная фаза	Исключить укладку чрезмерно охлажденной смеси	Температура смеси, заполнителей, воды, время транспортирования	Смесь поступает к укладке в безопасном температурном интервале, установленном проектом производства работ	Снижается потребность в резком нагреве после укладки
Фаза мягкого разогрева	Запустить устойчивое твердение без температурного удара	Мощность, ток, начальная скорость роста температуры	Температура растет без локальных скачков и опасного градиента	Предотвращается перегрев отдельных зон
Фаза стабилизации	Поддерживать активную гидратацию до требуемой зрелости	Температура ядра и поверхности, зрелость, сопротивление	Достигнута расчетная или контрольная прочность	Обеспечивается технологическая готовность конструкции
Фаза контролируемого охлаждения	Снизить риск термических напряжений	Скорость охлаждения, сохранение утепления, наружная температура	Температурный перепад не выходит за безопасный предел проекта	Сохраняется структура раннего цементного камня

Научная значимость фазной модели состоит в том, что она учитывает временную природу бетона. Бетон через 1 час, 6 часов и 24 часа - это не один и тот же материал. Он меняет пластичность, тепловыделение, проводимость, сопротивление деформациям и чувствительность к охлаждению. Поэтому режим, безопасный в середине выдерживания, может быть опасен в самом начале. И наоборот: слабый режим, допустимый в первые

минуты, может оказаться недостаточным ночью при усилении ветра и падении температуры наружного воздуха.

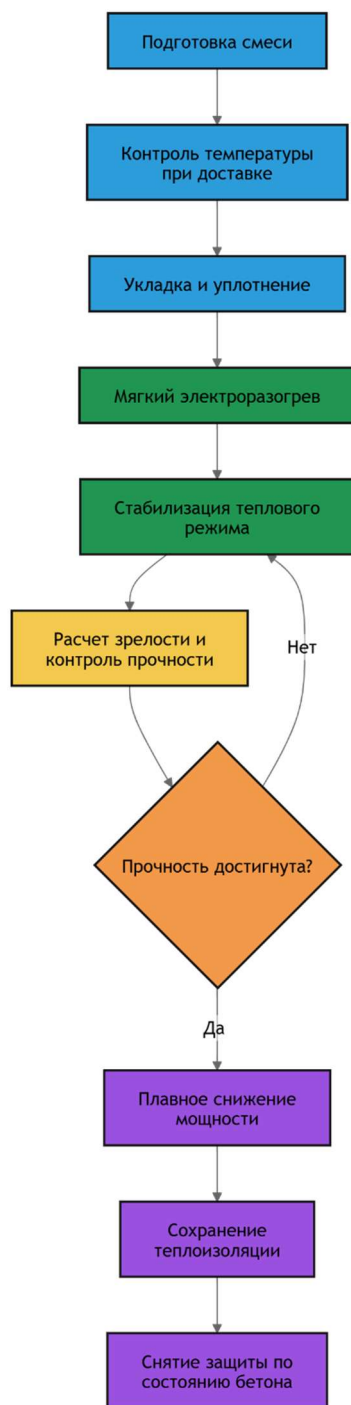


Рисунок 3 - Фазная траектория электронагрева бетонной смеси в зимнем бетонировании

Рисунок 3 подчеркивает, что завершение электронагрева не совпадает автоматически с отключением питания. После отключения начинается не менее ответственный этап - контролируемое охлаждение. Конструкция, набравшая раннюю прочность, но резко охлажденная с поверхности, может получить температурные напряжения. Для массивных элементов этот риск особенно заметен, потому что ядро сохраняет тепло дольше поверхности. Поэтому окончание прогрева должно сопровождаться сохранением теплоизоляции и контролем температурного перепада.

Обсуждение

Сопоставление источников показывает, что в научной литературе сформировались две параллельные логики развития зимнего бетонирования. Первая логика идет от классической технологии: утепление, противоморозные добавки, электропрогрев, нагреваемая опалубка, контроль температуры. Она опирается на практическую надежность, но часто страдает недостаточной точностью управления. Вторая логика идет от материаловедения и цифрового контроля: зрелость, температурные датчики, моделирование теплопереноса, проводящие цементные композиты, адаптивные алгоритмы. Она дает более точный инструмент, но требует квалификации, данных и дисциплины измерений.

Наиболее продуктивным является соединение этих логик. Электропрогрев без материаловедческого понимания превращается в силовую операцию. Материаловедческая теория без строительной технологичности остается лабораторной схемой. Поэтому развитие научных основ электроразогрева должно идти через инженерный компромисс: технология должна быть достаточно простой для площадки, но достаточно точной для управления структурообразованием бетона.

Особое значение имеет переход от календарного критерия к критерию состояния. Традиционная фраза «греть столько-то часов» удобна, но она не отражает реального состояния материала. При одинаковой длительности прогрева бетон может иметь разную зрелость из-за температуры смеси, расхода цемента, минеральных добавок, влажности заполнителей, ветрового охлаждения и тепловой защиты. Более корректный критерий – достижение заданной прочности или зрелости при подтвержденной температурной истории. Именно здесь метод зрелости становится связующим звеном между лабораторией и площадкой.

При этом нельзя преувеличивать универсальность метода зрелости. Он требует предварительной калибровки конкретной смеси, потому что разные цементы, добавки и минеральные компоненты имеют различную температурную чувствительность. Если зависимость «прочность – зрелость» взята из чужой смеси, она может дать ложную уверенность. Для ответственных конструкций зрелость должна сочетаться с контрольными образцами, неразрушающими методами, журналом прогрева и инженерной оценкой температурного поля.

Отдельная проблема – энергоэффективность. На строительной площадке электроразогрев часто оценивается по принципу «работает или не работает». Но современное строительство уже не может игнорировать энергетический след технологии. Избыточный обогрев, плохая теплоизоляция, неправильно выбранный шаг провода, нагрев воздуха вместо бетона и отсутствие обратной связи повышают стоимость работ. В этом смысле энергоэффективность не противоречит качеству. Напротив, качественно спроектированный режим обычно расходует меньше энергии, потому что тепло направляется в нужный объем и удерживается там до достижения требуемого состояния.

Перспективным направлением является применение проводящих цементных систем. Но здесь требуется осторожность. Добавление углеродных волокон, сажи или наноуглеродных материалов меняет не только проводимость, но и реологию, водопотребность, однородность, контактную структуру и стоимость материала. Такие решения нельзя механически переносить в обычное монолитное строительство без испытаний. Их рациональная ниша – специальные конструкции в холодных регионах, элементы с повышенными требованиями к ранней прочности, интеллектуальные материалы с функцией самонагрева или температурного самоконтроля.

Внутреннее противоречие технологии электроразогрева заключается в том, что бетон нужно прогреть достаточно быстро, чтобы защитить от замораживания, но достаточно мягко,

чтобы не нарушить структуру. Это противоречие не решается одной добавкой или одним трансформатором. Оно решается системой: состав смеси, схема нагрева, теплоизоляция, датчики, расчет зрелости, контроль прочности и дисциплина ведения журнала. Именно такая система превращает зимнее бетонирование из сезонного риска в управляемую технологию.

Практические рекомендации:

1. Электроразогрев следует проектировать не после выбора состава бетона, а одновременно с ним. Цемент, минеральные добавки, противоморозные компоненты, водоцементное отношение и подвижность смеси должны рассматриваться как факторы теплового режима.
2. Для каждой ответственной конструкции необходимо задавать не только длительность прогрева, но и температурную траекторию: минимальную допустимую температуру, максимально допустимую скорость нагрева, период стабилизации и порядок охлаждения.
3. Размещение датчиков должно учитывать геометрию конструкции. Один датчик в центре элемента не выявляет холодные кромки, углы, зоны около опалубки и участки интенсивного теплового отвода.
4. При электродном прогреве и прогреве проводом требуется контролировать не только температуру, но и ток, напряжение, сопротивление цепи. Изменение сопротивления является ранним признаком изменения влажностно-структурного состояния системы или нарушения контакта.
5. Метод зрелости целесообразно применять только после калибровки на конкретной бетонной смеси. Для ответственных работ его нужно дополнять контрольными образцами и неразрушающей диагностикой.
6. Завершение прогрева должно выполняться через фазу контролируемого охлаждения. Резкое отключение питания и снятие утепления после достижения ранней прочности увеличивают риск температурных напряжений.
7. Энергоэффективность необходимо закладывать в проект производства работ: правильная теплоизоляция, расчет шага нагревательных элементов и обратная связь по температуре часто дают больший эффект, чем увеличение мощности.
8. Проводящие бетоны с углеродными добавками следует рассматривать как перспективное направление, но не как универсальную замену традиционному электропрогреву. Их применение требует лабораторной проверки электросопротивления, прочности, реологии и долговечности.

Заключение

Электроразогрев бетонной смеси в технологии зимнего бетонирования должен рассматриваться как научно управляемый процесс, в котором электрическая энергия, тепловой баланс, гидратация цемента и набор прочности образуют единую систему. Простое повышение температуры не гарантирует качества, если не контролируются температурные градиенты, изменение сопротивления, зрелость бетона и условия последующего охлаждения.

Наиболее обоснованным направлением совершенствования является адаптивная трехконтурная модель: тепловой контур отвечает за температурную безопасность, электрический контур - за устойчивость выделения джоулева тепла, прочностной контур - за связь температурной истории с достижением критической и технологической прочности. Такая модель позволяет снизить риск раннего замораживания, локального перегрева, избыточного энергопотребления и преждевременного прекращения тепловой защиты.

Научная новизна предложенного подхода состоит в переходе от режима «нагревать бетон заданное время» к режиму «вести бетон по расчетной траектории

структурообразования». Практическая ценность выражается в возможности проектировать зимнее бетонирование не по усредненной схеме, а по состоянию конкретной смеси, конкретной конструкции и конкретным климатическим условиям. Для дальнейшего развития темы наиболее перспективны цифровые журналы прогрева, автоматизированное управление трансформаторными ступенями, совмещение метода зрелости с неразрушающей диагностикой и применение проводящих цементных композитов в конструкциях, работающих в холодных регионах.

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Pedagogical Sciences

Stereotype as the basis of cultural value (using the example of nomenclature names)

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Abstract

The article examines the concept of stereotype as the basis of the cultural value of nomenclature names, analyzes such properties as social conditioning, stability and schematicity. The text acts as a means of objectification of a stereotype.

Keywords: nomenclature names, cultural value, stereotype.

The research is carried out within the framework of the linguistic and cultural direction in order to study the cultural value of nomenclature names and is focused on describing not the realities, but the images existing in the modern linguistic consciousness and behind the nomenclature and names. Following O.N. Ivanishcheva, we refer to the nomenclature names of consumer goods, medicines, food, household chemicals and perfumes, clothing, transport, etc., for example: car "Chevrolet", whiskey "Jameson", bread "Sarafee", toothpaste "Marvis" [4, p. 75].

The understanding of the fact that an individual's belonging to a certain culture is determined by the presence of "a basic stereotypical core of knowledge that repeats itself in the process of socialization of an individual in a given society" [5, p. 14], a certain unified information base, has long been reflected in research on linguoculturology. The nomenclature name, as a proper name, can act as an information-rich unit, being a unique "bank of meanings". As noted by I.E. Ratnikova, it is potentially open to various kinds of semantic increments and transformations, in particular, the transformation of encyclopedic knowledge into elements of linguistic consciousness [6, p. 11]. Nomenclature names are actively used in speech and form an integral part of the everyday linguistic environment. One of the main properties of the world of everyday life is self-evidence, i.e. ordinariness for every person, which is reflected in the words habitual, typical, normal, permanent, natural, etc. In our opinion, the basis of the cultural value of nomenclature names are those standardized, culturally specific representations of the subject, some collective images, usually emotionally colored and highly stable, which are called stereotypes [3, p. 1150]. The purpose of this article is to consider the concept of stereotype as the basis of the cultural value of the studied units.

An analysis of various approaches to the study of a stereotype shows that the set of characteristic properties that a stereotype is endowed with varies (see, for example, 1), but among them one can single out those properties that are key in determining the cultural value of the studied units.: 1) social conditioning, sustainability, and 3) schematicity.

The stereotype is socially conditioned, i.e. this phenomenon is a product of the activity of a social community. The bearer of a stereotype is a collective subject, which can be both the entire cultural community and its individual groups, which means that stereotypes can be mass and group. The existence of various group stereotypes indicates stereoscopicity, or multiplicity, of perception and evaluation of the same subject by representatives of different groups (social, professional, age) [7, p. 68]. For example, stereotypical ideas about "Viceroy", "Camel", "Chesterfield" and "Pall Mall" cigarettes and "Tigress", "Cachet" and "Royal Secret" perfumes differ in the minds of native speakers of different generations.

The stereotype remains unchanged for a relatively long period of time and is therefore characterized by a high degree of stability, which is ensured by the repeated repetition of the connection of the feature with the object. The stereotype does not change immediately, but as a result of the accumulation of a large amount of refuting information. In this case, there are two possible scenarios for the development of the situation: 1) the complete destruction of the stereotype due to its inconsistency with social realities, for example, the stereotype of the perception of the Volga car as an official car disappears, as well as the idea of it as a prestigious car, which is an indicator of a high social status; 2) changing only the rating mark, for example, a high assessment of the technical characteristics of the Volga car, its the appearance has changed to the opposite.

The study of stereotypical representations in dynamics defines the time limits of this study - the middle of the 20th and the beginning of the 21st centuries, since we are talking about decades during which fundamental changes took place in the country, affecting the daily life of a person.

A stereotype, as a schematized representation, captures the most significant, vivid signs and objects that reflect ideas about reality and reveal its value as a cultural sign. Such signs are not reflected in dictionaries. Currently, there is no separate dictionary of nomenclature names, and when these units are included in general dictionaries, the selection is not always consistent. For example, the Database contains the names of cars such as Volga, Zhiguli, Zaporozhets, KamAZ, etc., and the name of the Moskvich car is not included. In addition, the dictionary text is a special type of text: it captures the signs of the minimum content of the word, for example: Zaporozhets. The automobile of the Zaporizhia plant [2, p. 339]. The dictionary entries in the encyclopedic dictionaries are distinguished by a detailed description of the technical characteristics of the car. However, we are not so much interested in encyclopedic information as in the specifics of the functioning of this name in the discourse of the Russian linguistic and cultural community.

The texts of fiction and journalistic literature reflecting the real state of the discourse of the Russian cultural community serve as a source of material for the study of stereotypes prevailing in the modern consciousness. The appeal to the text is natural, since the sign and realities existing in the memory of native speakers are realized in speech activity, being fixed in oral and written texts. Text is a means of objectifying stereotypes and one of the most convenient forms for their research.

The basis for highlighting a feature may be the presence of a certain number of contexts of the use of a nomenclature name that actualize the cultural value. The criterion of frequency is important, since the frequency of use indicates the stability of the idea, about stereotyping. Constructions that indicate the source of what is being reported or evaluate it from the point of view of ordinariness can also act as actualizers, for example: as you know, as a rule, as we know, it is considered, they say, by nickname, etc. For example: We never smoked Prima, Belomor, or Yenisei, because it was considered a smoke for hard workers. And we were punks, that is, the free

aristocracy of the late 20th century [8, p. 26].

In order to form stereotype, it takes a certain period of time during which things are "experienced" by people, included in the social hierarchy of values. Therefore, the so-called spontaneous stereotypes are of the greatest interest to us as they are more stable, require more time and formation, are unintentional and objective, as they arise from everyday practice, as a result of assimilation of one's own and others' experience. They, unlike artificial stereotypes, which are created purposefully and replicated with the help of mass media, form the basis of the cultural value of nomenclature names.

And so, a stereotype is a stable cultural and national idea of a subject that combines a sensory-visual image (descriptive features) and an attitude (evaluative features). By stereotype, we mean a habitual image, habitual associations, and a person's habitual attitude to a phenomenon or object, and the words ordinary, repetitive, and generally accepted are used as synonyms for the word stereotypical.

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Адаптивная образовательная платформа как средство формирования методического мышления будущих учителей информатики

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Аннотация

Адаптивные образовательные платформы предоставляют новые возможности для формирования методического мышления у будущих учителей информатики, обеспечивая персонализированное обучение, интерактивность и рефлексивную поддержку образовательного процесса. В статье рассматриваются понятие адаптивного обучения, принципы персонализации и психолого-педагогические механизмы, обеспечивающие эффективность обучения. Предлагается теоретическая модель формирования методического мышления в адаптивной цифровой среде, включающая целевой, содержательный, технологический и диагностический компоненты. Особое внимание уделяется практическим аспектам: интеграции платформы в образовательный процесс, организации рефлексивной работы студентов, мониторингу и оценке уровня сформированности методического мышления. Статья ориентирована на педагогов, исследователей в области образовательных технологий и разработчиков цифровых платформ. Практическая значимость заключается в обосновании педагогических условий и инструментов для эффективного использования адаптивных технологий в профессиональной подготовке учителей информатики.

Ключевые слова: адаптивная платформа, методическое мышление, учитель информатики, персонализация обучения, педагогическая модель

Цифровые технологии и платформы с адаптивными функциями становятся важным инструментом формирования методического мышления будущих учителей информатики. Адаптивная среда позволяет учитывать индивидуальные особенности студентов, обеспечивать интерактивную и рефлексивную поддержку, стимулировать развитие компетенций.

Цель статьи разработать теоретическую модель формирования методического мышления будущих учителей информатики с использованием адаптивной образовательной платформы.

Адаптивное обучение представляет собой педагогический подход, при котором образовательная среда гибко подстраивается под индивидуальные потребности, уровень знаний и темп усвоения материала каждым студентом (Johnson et al., 2020; UNESCO, 2018). Основной принцип адаптивного обучения заключается в персонализации содержания и

заданий, что позволяет учитывать уникальные особенности каждого обучающегося и оптимизировать процесс усвоения знаний. Важной особенностью является динамическая адаптация учебных материалов: платформа корректирует сложность и объем заданий в зависимости от результатов студента, обеспечивая непрерывную обратную связь. Кроме того, адаптивные подходы предполагают интеграцию рефлексивных упражнений, которые помогают студентам осознавать собственные достижения, оценивать эффективность действий и планировать дальнейшее обучение.

Адаптивные образовательные платформы обладают широким спектром дидактических возможностей. Они позволяют моделировать разнообразные учебные ситуации, которые имитируют реальные образовательные и профессиональные задачи. Через проектную и исследовательскую деятельность платформа способствует развитию методического мышления, стимулируя студентов самостоятельно принимать решения, планировать деятельность и анализировать результаты. Дополнительно адаптивные платформы включают интерактивные ресурсы и симуляции, которые делают процесс обучения более наглядным и вовлекающим. Встроенные механизмы мониторинга прогресса студентов позволяют преподавателю своевременно корректировать траектории обучения и адаптировать образовательные задания под конкретные потребности обучающихся.

Эффективность адаптивного обучения обеспечивается использованием психолого-педагогических механизмов, направленных на мотивацию, развитие саморегуляции и формирование метакогнитивных навыков. Индивидуальные цели стимулируют студентов к активной учебной деятельности, а включение рефлексивных заданий способствует развитию критического анализа и способности оценивать собственные результаты. Платформа поддерживает сотрудничество между студентами и коллективный анализ кейсов, что усиливает коммуникативные и аналитические компетенции. Особое внимание уделяется интеграции метакогнитивных стратегий, которые направлены на формирование проектировочных и рефлексивных компонентов методического мышления, позволяя будущим учителям информатики самостоятельно планировать учебные процессы и оценивать их эффективность.

Предлагаемая теоретическая модель формирования методического мышления будущих учителей информатики в адаптивной образовательной среде представляет собой комплексную систему, состоящую из четырёх взаимосвязанных компонентов: целевого, содержательного, технологического и диагностического.

Целевой компонент модели определяет задачи формирования методического мышления и ключевых педагогических компетенций у студентов. Он включает формулирование образовательных целей, ориентированных на развитие когнитивных, проектировочных, операциональных и рефлексивных навыков, необходимых будущему учителю для успешного проектирования и организации учебного процесса.

Содержательный компонент охватывает учебные материалы, методические кейсы, практические задания и симуляции, обеспечивая практико-ориентированное освоение педагогических ситуаций. Данный компонент позволяет студентам применять теоретические знания в реальных образовательных контекстах, формируя навыки анализа, планирования и критической оценки педагогических решений.

Технологический компонент модели связан с функционалом адаптивной образовательной платформы. Он обеспечивает персонализацию обучения, динамическую адаптацию заданий и постоянную обратную связь. Именно технологический аспект позволяет интегрировать цифровые инструменты и интерактивные ресурсы в образовательный процесс, делая его гибким и ориентированным на индивидуальные особенности обучающихся.

Диагностический компонент включает инструменты оценки и мониторинга уровня сформированности методического мышления, такие как анкеты, тесты, учебные проекты и рефлексивные дневники. Он обеспечивает возможность отслеживать прогресс студентов, выявлять пробелы в освоении компетенций и корректировать траекторию обучения, создавая обратную связь между всеми элементами модели.

Таким образом, предложенная структурно-функциональная модель демонстрирует взаимосвязь между целями формирования компетенций, содержательными ресурсами, технологической поддержкой и механизмами диагностики, обеспечивая комплексное и системное развитие методического мышления в условиях адаптивной образовательной среды.

Схема 1. Структурно-функциональная модель формирования методического мышления в адаптивной среде



На схеме центральный блок символизирует методическое мышление, окружённое четырьмя взаимосвязанными сегментами: целевой, содержательный, технологический и диагностический. Стрелки отражают взаимное влияние компонентов и непрерывную обратную связь, обеспечивающую динамичное развитие компетенций студентов.

Эффективное формирование методического мышления будущих учителей информатики в условиях адаптивной образовательной среды требует создания комплекса педагогических условий, направленных на системное развитие компетенций студентов. В первую очередь, значимым условием является методическое сопровождение, которое осуществляется преподавателями и наставниками. Оно предполагает организацию консультаций, предоставление рекомендаций по проектной и исследовательской деятельности, а также сопровождение процесса рефлексии студентов, что обеспечивает качественную интерпретацию образовательного опыта и стимулирует профессиональное саморазвитие.

Следующим важным аспектом является использование аналитических возможностей адаптивной платформы для мониторинга прогресса студентов и корректировки траекторий обучения. Данный подход позволяет преподавателям своевременно выявлять зоны

затруднений и адаптировать содержание и сложность заданий в соответствии с индивидуальными особенностями каждого обучающегося.

Проектная деятельность выступает ключевым механизмом формирования методического мышления, поскольку студенты получают возможность разрабатывать учебные сценарии и планировать уроки с использованием цифровых ресурсов. Такая практика способствует интеграции теоретических знаний и практических навыков, формируя способность к самостоятельному планированию и реализации образовательных проектов.

Рефлексивная практика является ещё одним существенным условием реализации модели. Она включает критический анализ собственной педагогической деятельности, оценку успешности реализации проектов, выявление ошибок и поиск способов их корректировки. Этот компонент обеспечивает развитие рефлексивного и проектировочного аспектов методического мышления и формирует у студентов привычку к систематическому самоанализу профессиональной практики.

Анализ международных и отечественных исследований (Johnson et al., 2020; Shulman, 1987) демонстрирует, что внедрение адаптивных образовательных платформ способствует не только повышению цифровой компетентности студентов, но и активному развитию методического мышления. Особое внимание при этом уделяется проектировочному и рефлексивному компонентам, которые критически важны для профессиональной подготовки учителя информатики.

Применение адаптивных платформ в педагогических вузах позволяет создать образовательную среду, ориентированную на индивидуальные потребности обучающихся, обеспечивая персонализированные траектории обучения. Это создаёт условия для формирования гибкого, компетентного и цифрового подкованного педагога, способного эффективно организовать учебный процесс с учётом разнообразных образовательных контекстов и особенностей учеников.

Анализ и обобщение теоретических и практических данных позволяют сделать следующие выводы:

1. Адаптивные образовательные платформы являются эффективным инструментом персонализации обучения и способствуют формированию методического мышления будущих учителей информатики.
2. Предложенная структурно-функциональная модель объединяет целевой, содержательный, технологический и диагностический компоненты, обеспечивая комплексный подход к развитию профессиональных компетенций.
3. Педагогические условия реализации модели — методическое сопровождение, проектная деятельность и рефлексивная практика — создают необходимую среду для системного формирования методического мышления.
4. Практическая значимость модели заключается в её возможности использоваться для модернизации образовательных программ педагогических вузов и внедрения адаптивных платформ в подготовку будущих педагогов, что обеспечивает соответствие современным требованиям цифровой образовательной среды.

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THE EFFECTIVENESS OF THE iSL COLLECTIVE PLATFORM IN ENHANCING ENGLISH GRAMMAR ACQUISITION: AN EMPIRICAL STUDY

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Аңдатпа

Бұл зерттеуде iSL Collective онлайн платформасының ағылшын тілін оқытудағы грамматикалық дағдыларға әсері қарастырылды. Эксперимент 24 студентпен жүргізіліп, олар екі топқа бөлінді: 12 студент дәстүрлі әдіспен оқытылды, ал 12 студент iSL Collective платформасын қолданды. Зерттеу соңғы бес жылдағы зерттеулерге негізделген. Нәтижелер платформаның грамматиканы меңгеруге оң әсерін, мотивацияны арттыру мен дербес оқу дағдыларын дамытатынын көрсетті.

Кілт сөздер: iSL Collective, грамматика, EFL, цифрлық оқыту, интерактивті сабақ, дербес оқу

Аннотация

В данном исследовании рассматривается влияние онлайн-платформы iSL Collective на овладение грамматическими навыками английского языка. Эксперимент проводился с 24 студентами, разделёнными на две группы: 12 студентов обучались традиционным методом, 12 студентов использовали платформу iSL Collective. Обзор литературы основан на исследованиях последних пяти лет. Результаты показали положительное влияние платформы на усвоение грамматики, повышение мотивации и развитие самостоятельного обучения.

Ключевые слова: iSL Collective, грамматика, EFL, цифровое обучение, интерактивные занятия, самостоятельное обучение

Annotation

This study investigates the effectiveness of the iSL Collective online platform in enhancing English grammar acquisition. The experiment involved 24 students divided into two groups: 12 students received traditional grammar instruction, while 12 students used the iSL Collective platform. The study also reviews research from the last five years. Results indicate that the platform positively influences grammar learning, increases motivation, and develops learner autonomy.

Keywords: iSL Collective, grammar, EFL, digital learning, interactive lessons, learner autonomy

1. Introduction

English grammar instruction is a critical yet challenging aspect of language learning for EFL students. Traditional grammar teaching methods often rely on rule memorisation and decontextualised written practice, which may limit learner engagement and communicative skill development. The rapid growth of digital learning environments has introduced educational platforms that offer interactive learning experiences designed to complement traditional classroom instruction.

The iSL Collective platform provides teachers and learners with video-based lessons, practice exercises, and contextualised tasks that support student engagement and reinforce grammatical competence. This study aims to evaluate the effectiveness of iSL Collective for grammar acquisition by comparing outcomes between an experimental group that used the platform and a control group taught through conventional methods.

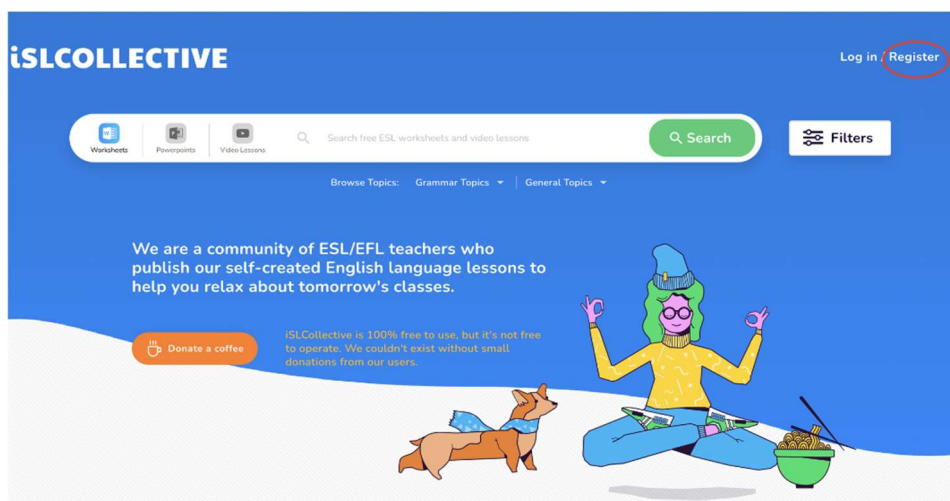
2. Literature Review

Over the past five years, research examining digital learning environments in second language acquisition has highlighted the advantages of interactive online tools for grammar development. Li (2018) found that video-based grammar instruction enhances learner engagement and supports deeper understanding by presenting linguistic rules within meaningful communicative contexts. Chen (2019) emphasised that computer-assisted language learning (CALL) systems can increase student motivation, particularly when tasks are interactive and scaffolded.

Smith (2020) demonstrated that learners who engaged in interactive digital exercises made fewer grammatical errors and showed higher accuracy in written outputs compared to peers in traditional classrooms. Ahmed (2021) argued that online platforms foster learner autonomy by enabling students to self-pace their practice and review materials as needed. González (2022) reported that the use of multimedia formats, including videos and interactive activities, led to improved retention of grammatical structures. Finally, Patel (2023) showed that digital platforms enhance learner engagement and communicative competence through adaptive learning pathways tailored to individual needs. Overall, recent studies consistently support the pedagogical value of digital learning tools for grammar instruction, particularly for developing learner autonomy and engagement in EFL contexts.

3. Methodology

The study employed a mixed-methods approach, combining quantitative assessment through grammar tests with qualitative feedback from questionnaires and observations. This approach allowed the researchers to capture both measurable improvement in grammar proficiency and the subjective experiences of learners using the iSL Collective platform.



3.1 Participants

Twenty-four ($N = 24$) beginner-level EFL learners participated in this study. Participants were randomly divided into:

- Control group ($n = 12$): received traditional grammar instruction
- Experimental group ($n = 12$): engaged in grammar learning using the iSL Collective platform

3.2 Instruments

- Pre-test and Post-test: Grammar proficiency tests to measure improvement
- Questionnaire: Assess learner motivation and autonomy

- Classroom observation checklist: Document instructional engagement

3.3 Procedure

Over a four-week period, both groups attended two lessons per week. The control group was taught grammar using a conventional textbook and teacher-led explanations. The experimental group used iSL Collective’s curated grammar video lessons and interactive exercises alongside in-class discussion and practice. After the intervention, all participants completed the Post-test and motivation questionnaire.

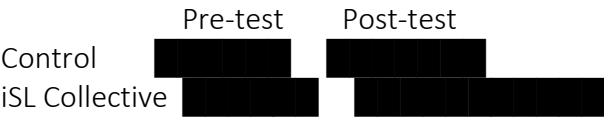
4. Results

4.1 Quantitative Results (Graphical Representation)

The table below summarises group performance in Pre-test and Post-test scores (%):

Group	Pre-test (%)	Post-test (%)	Gain (%)
Control (n=12)	61.0	70.8	+9.8
iSL Collective (n=12)	60.8	83.5	+22.7

Graphical Summary:



The experimental group using iSL Collective showed a significantly higher increase in grammar proficiency compared to the control group.

4.2 Qualitative Findings

- Motivation: 88% of participants in the experimental group reported higher engagement due to interactive activities.
- Autonomy: 80% indicated improved self-paced learning and confidence.
- Perceived Understanding: 83% felt grammar was easier to grasp with video-supported instruction.

Discussion

The results indicate that learners using the iSL Collective platform outperformed peers receiving traditional grammar instruction. The multimedia features and contextualised practice likely contributed to better comprehension and retention of grammatical structures. Additionally, the platform’s interactive exercises appeared to raise motivation and foster learner autonomy, consistent with findings from recent CALL research. The combination of visual input, immediate feedback, and self-regulated learning pathways makes iSL Collective a valuable supplement to conventional English grammar teaching.

6. Conclusion

This study provides evidence that the iSL Collective platform enhances English grammar acquisition among EFL learners. The platform not only improved learners’ grammatical performance but also supported increased motivation and independent learning skills. Future research should consider longer intervention periods and larger sample sizes to validate these findings further.

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From Knowledge to Interaction: Structuring a Textbook Unit for Sociocultural Development

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The modern paradigm of foreign language education in Kazakhstan is largely determined by the requirements of state educational standards. Among the key goals of bachelor's degree programs in foreign language education is the formation of students' ability to engage in intercultural interaction. This ability, in turn, is fundamentally based on the mastery of sociocultural competence (Safonova, 2014, p. 15).

As Safonova (2014) rightly points out, sociocultural education through a foreign language cannot be reduced to simply familiarizing students with texts about a culture. It requires involving learners in the process of comparing cultures and developing their skills of interpretation and critical analysis. However, an analysis of contemporary textbooks reveals that many authors still limit themselves to presenting isolated country-specific facts. Such an approach, while providing useful information, does not adequately prepare students for real-world communication, where cultural knowledge must be applied flexibly and appropriately (Kegeyan, 2015).

The present article seeks to address this gap by proposing a framework for designing textbook units that foster sociocultural competence. Rather than merely analyzing existing materials, the aim is to offer practical guidance for textbook authors and curriculum developers.

Thus, building on the understanding of sociocultural competence as a multidimensional concept, a three-stage framework for unit design is proposed. Each stage serves a distinct purpose and features specific types of tasks that collectively support the development of all competence components.

The purpose of the preparation stage is to equip students with the foundational knowledge they will need for subsequent engagement with cultural content. This includes both linguistic knowledge, particularly culturally marked vocabulary, and background knowledge about the topics to be explored. In terms of vocabulary work, tasks at this stage should go beyond simple memorization. Students need opportunities to encounter new lexical items in multiple contexts, to explore their meanings through synonyms and antonyms, and to practice using them in sentences of their own creation. Phonetic work is also important, as correct pronunciation contributes to confident communication about cultural topics.

The preparation stage should also activate students' prior knowledge and stimulate curiosity about the topic. Brief pre-reading questions or discussions can serve this purpose, encouraging students to recall what they already know and to formulate questions about what they would like to learn.

The active engagement stage forms the core of the unit and should provide multiple opportunities for students to develop their interpretive, analytical, and interactive skills. This stage typically involves work with authentic or semi-authentic texts, followed by a variety of tasks that target different competence components.

Reading texts should be carefully selected for their cultural richness and relevance to the unit theme. In the case of a unit on history and geography, texts that trace the historical development of different countries can serve multiple purposes. They provide factual information,

introduce culture-specific concepts and terminology, and model ways of talking about historical processes.

Following exposure to such texts, students need opportunities to engage with the content in meaningful ways. Tasks that require independent research on culture-specific terms transform students from passive recipients of information into active investigators of culture. By using reliable internet sources to find definitions of cultural concepts students develop research skills while deepening their cultural knowledge.

Comparative tasks are particularly valuable at this stage. Asking students to classify information by categories or to compare cultural characteristics across countries requires them to move beyond simple comprehension to analysis and synthesis.

Role-playing activities add an interactive dimension to the active engagement stage. By simulating situations such as a museum dialogue between a tourist and a guide, students practice using their cultural knowledge in communicative contexts. These activities require them to adapt their language to different roles and purposes, thereby developing sociolinguistic awareness alongside cultural knowledge.

The most sophisticated tasks at this stage involve problem-based cases that confront students with the complexities of real intercultural encounters. A well-designed case presents a situation where cultural differences in communication styles, expectations, or values create challenges that must be navigated. Students analyze the situation from multiple perspectives, consider the cultural factors at play, and propose strategies for effective interaction.

The reflection stage is essential for consolidating learning and helping students connect new knowledge to their personal experience and future practice. Without structured reflection, there is a risk that cultural learning remains superficial and disconnected from students' lives.

Reflective tasks can take various forms. Comparing information across different sources, such as a video and a written text, encourages students to think critically about how cultural content is presented and to identify gaps or differences in coverage. Questions that ask what students found surprising or interesting prompt them to notice what stood out for them personally.

Writing tasks that structure reflection around specific questions are particularly effective. Asking students to identify what they already knew, what new information they discovered, and how this knowledge might help them in future intercultural communication encourages them to connect learning with personal relevance.

By the end of the reflection stage, students should have not only expanded their knowledge but also developed a clearer understanding of why that knowledge matters and how it can be applied. This sense of personal significance is what transforms information into competence.

The framework proposed above suggests several criteria that can be used to evaluate textbooks from the standpoint of their potential to develop sociocultural competence. These criteria can guide authors in designing new materials and assist educators in selecting among existing options.

- The first criterion concerns the selection and treatment of culturally marked vocabulary. Effective textbooks include systematic vocabulary work that goes beyond definition to explore cultural connotations and provide multiple opportunities for contextualized practice;
- The second criterion relates to the inclusion of comparative tasks. Textbooks should regularly require students to compare elements of the target culture with their own culture, thereby developing the ability to see cultural phenomena in relation to one another;
- The third criterion involves the use of authentic or semi-authentic materials. Students need exposure to genuine instances of language use in cultural context, whether through written texts, audio recordings, or video materials;

– The fourth criterion concerns the modeling of intercultural communication. Textbooks aimed at the development of sociocultural competence should include role-plays, case studies, and simulations that require students to apply their cultural knowledge in interactive situations;

– The fifth criterion relates to the inclusion of structured reflection. Textbooks should provide opportunities for students to consolidate their learning, connect new knowledge with prior understanding, and consider the personal significance of what they have learned.

Thus, this article has proposed a framework for designing textbook units that genuinely foster sociocultural competence among foreign language learners. The framework emphasizes the need to move beyond the presentation of isolated cultural facts toward a more integrated approach that develops all components of sociocultural competence in tandem.

The three-stage structure of preparation, active engagement, and reflection provides a coherent organizing principle for unit design. Each stage serves a distinct purpose and features specific types of tasks that collectively support sociocultural development.

It is hoped that the criteria proposed in this article will prove useful both for textbook authors seeking guidance in their work and for educators tasked with selecting materials for their students. Further research might usefully explore how students actually experience and learn from textbooks designed according to these principles, as well as how the framework might be adapted for different educational contexts and proficiency levels.

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Methods of forming socio-cultural competence of high school students at the lessons of English via Internet technologies

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Annotation

Abstract: This article examines the methodology for developing the socio-cultural competence of senior secondary school students in English language lessons through the use of Internet resources. The essence and significance of socio-cultural competence is described, and effective approaches to its development—such as authentic video materials, web-quest technology, blogging, and virtual cultural exchange—are analyzed. The ways of implementing each approach are explained with specific examples, and their impact on students' understanding of other cultures through a foreign language, as well as on the improvement of their communicative skills, is discussed.

Keywords: socio-cultural competence, internet resources, English language, authentic materials, web quest, blog, virtual exchange.

Research objective: to systematically examine the possibilities of internet-based learning materials and online platforms in developing socio-cultural competence of senior school students and to propose practical ways of their effective use in English language lessons.

Introduction

In the context of today's globalization and the information society, one of the main goals of teaching a foreign language is the formation of students' personalities who can communicate on an equal footing with the cultures of the world, capable of intercultural communication. Teaching a foreign language is not limited to teaching language rules and speech skills, but involves introducing the traditions, beliefs, history and culture of the people who speak that language. In other words, the student needs to master not only lexical and grammatical knowledge, but also cultural information that is the carrier of the language.

From this point of view, let us dwell on the concept of socio-cultural competence. According to the definition of researchers, socio-cultural competence is the ability to master the folk culture of the language being learned, the Customs and rules of etiquette of that people, social stereotypes, history and cultural values, as well as the ability to use them correctly in communication. This competence is recognized as the most important component of communicative competence in a foreign language. It is stated in scientific works that the complex of knowledge constituting socio-cultural competence consists of three main blocks: 1) linguocultural Education (National-Cultural semantics of language units, phraseology, nonverbal communication patterns, etc.), 2) socio-psychological education (norms and etiquette of behavior in communication of a language society), 3) cultural and cognitive education (information on the history, geography, literature and art, traditions of the object language country).

The formation of this complex of knowledge, skills and abilities in the student is a prerequisite for full – fledged intercultural communication. However, in traditional learning conditions, mastering the socio-cultural aspects of a foreign language is not an easy task. Although it is possible to recognize a different culture through role-playing games in the classroom and

examples in the textbook, many students may not always experience it on an emotional or personal level in their personal experience. For example, no matter how many places a teacher describes the customs of another people, it is often difficult for students to perceive it as memorized information and intertwine in their essence. Even in role-playing games, students often continue to use the patterns of behavior of their culture, and elements of foreign culture remain at the level of "knowledge in the book".

In such conditions, the integrated introduction of internet resources into the educational process opens up new opportunities for the formation of socio-cultural competence. Scientists and methodologists point to the internet as one of the most effective innovative tools for teaching a foreign language. The internet is a powerful communication tool that allows people to exchange information and share worldview data among themselves. The online environment allows students to communicate with language carriers in real language situations, thereby experiencing a different culture in personal experience. Through the internet, students can find original materials from all over the world and get acquainted on their own, communicate directly with their foreign peers, and begin to understand more deeply the way of thinking and values of this people. This strengthens the motivation to study a foreign language and contributes to a conscious understanding that language is not only an academic subject, but also a means of living communication.

It is at this point that the relevance of the topic of the article is most clearly manifested. The purpose of the study is to analyze and present an effective methodology for the formation of socio – cultural competence of high school students in English lessons, especially to show the importance of using internet resources. To achieve this goal, the following tasks were set:

- Theoretical description of the content and essence of socio-cultural competence;
- Identify the main methods of developing socio-cultural knowledge and skills via the internet in English lessons;
- Show specific examples of ways to implement each method in a practical way;
- Discuss the effectiveness of the proposed methodology and make recommendations for its implementation in the educational process.

The main part.

With the effective use of internet technologies, it is possible to develop the socio-cultural competence of students in English lessons. Below we will analyze several methods that are recognized as useful in achieving the same goal, focusing on each separately: working with authentic videos, the web quest method, online blogging and virtual cultural exchange. The content of each method, the ways of its implementation and its role in socio-cultural education are outlined with specific examples.

Use of authentic video materials.

Authentic video is the original video materials prepared by representatives of the country where they speak the language, which are not specially adapted for educational purposes. They can include an excerpt from feature films, a documentary, a clip from a news story, interviews, vlog posts, etc.. Such videos allow students to visually and hear the way of life, language environment, cultural values and norms of behavior of this people. That is, sitting in a study classroom, it creates conditions for virtual immersion in the cultural space of another country. Through the video, students will be able to understand the features of nonverbal communication, such as gestures, facial expressions, and keeping distance. This is an integral part of socio-cultural competence, because in the communication of each people, non-verbal actions have their own meaning.

To use authentic video materials in the classroom, the teacher selects a video in advance that corresponds to the language level of students and the topic, and develops tasks related to it. Example: let's say a short video in English called " Holiday traditions around the world " is obtained.

The roller shows the features of the celebration of traditional holidays of different countries (including England). Before showing it, the teacher can guide the students, such as "compare our Nauryz holiday and the English Christmas". During the viewing, students will pay attention to festive rituals in a foreign country, clothing patterns, wishes and ways of greeting people. After the show, a discussion is held in the classroom and questions are asked: "what was new to you in the English Christmas tradition?", "Is there a ritual similar to it in our culture?", "How did the behavioral features of foreigners (tone of voice, gestures, expression of emotions, etc.) that you noticed in the video affect your mood? "I'm sorry." Through this analysis, students not only learn new phrases, but also experience the culture of other people on an emotional level and learn to express their point of view. Authentic videos thus open the way to a comprehensive knowledge of the essence of the English-speaking population and increase students' interest in learning a foreign language.

Web quest technology.

A web quest is a kind of educational project that encourages students to conduct research on a specific issue using sources of information on the internet. During the web quest, the teacher prepares a list of websites, articles or other resources that are relevant to a specific topic in advance and sets specific tasks for students. As students surf the internet, they independently search for the necessary data, select and use it to complete the task. The web quest method develops students' critical thinking, problem – solving and self-learning skills, and most importantly, it makes them work with real cultural and cultural information.

Example: let's say a teacher organized a web quest on the topic "Discovering great Britain: A WebQuest". The class is divided into several groups, and each group is given a small research task related to the culture and lifestyle of Great Britain. Group I: "everyday life and manners of the British"; Group II: "virtual tour of historical places in the UK"; Group III: "national holidays and traditions of their Holding"; Group IV: "subcultures of modern British youth (music, style of clothing, manner of communication)". Each group is offered well-known sites where you can get information in English (for example, the site of the British encyclopedia, news portals, blogs for young people, etc.). Students collect and systematize the necessary data from these sources. Then they present the collected materials to the class in the form of a poster, slide or small report.

Blogging (online diary).

Blog is a platform for publishing posts and sharing thoughts in the form of a personal page in the internet space. In recent years, the method of blogging has become widespread in the field of Education. The use of a blog in English lessons not only develops students' written speech skills, but also creates conditions for their mutual exchange of cultural experience.

Example: a teacher can involve class students in blogging in English by joining an international online community. For example, let's say students open their own blog under the name "cultural exchange diary" (cultural exchange diary) and publish an entry on a specific topic once a week. Topics should correspond to the curriculum and be of cultural content: "traditions in my family", "how do we spend our free time? Topics such as", "my favorite national dish", "hospitality in the Kazakh people" are given by the teacher as a preliminary recommendation. Students write a short essay-note in English about their life and cultural environment on each topic. Then read and comment on the blog posts of other students in the class. If there is an opportunity, you can also exchange blogs with peers abroad-for example, English – speaking students also blog on these topics, and students from both countries read each other's posts, ask questions and write comments.

Blogging helps students freely express their thoughts, improve their writing style in a foreign language. The main thing is that they introduce their culture in English and gradually begin to understand the way of life of representatives of other cultures. Initially, a Kazakh student may see strange things in the blog of a friend abroad (for example, the value of personal life in Western

countries, features in the relationship between parents and children, etc.), and a foreign reader may recognize the original nature of Kazakh culture and ask questions. As a result of such a virtual dialogue, both sides will evaluate their culture from a new angle and take a step towards getting rid of their stereotypes. The blog platform builds students' critical reasoning and cultural reflection skills, in addition to their writing knowledge.

From a technical point of view, the use of blogs is quite acceptable: today there are free platforms such as WordPress, Blogger, Medium, where students can publish interesting posts decorated with the addition of a photo, video along with text. The teacher should explain the rules of blogging, internet security measures in advance, and conduct regular monitoring. It is also important to make sure that blog Discussions take place in an ethical, friendly atmosphere. It is proved in practice that with proper organization, through blogging, students develop not only the ability to write in English, but also openness to other cultures and communicative solidarity.

Virtual cultural exchange.

Online communication with direct language carriers is one of the most effective ways to develop socio-cultural competence. If earlier students had limited opportunities to communicate with foreigners (for example, to meet only visitors to their school), today, thanks to the internet, you can find friends from anywhere in the world. By virtual cultural exchange, we mean the long-term interaction of students from different countries through an online platform. Such communication takes place in various forms, such as electronic correspondence, video communication (video conferencing), social network groups, joint online projects. Example: you can organize a project "Pen pal email exchange" (friendly correspondence) between foreign students studying the Kazakh language and Kazakh students studying English. Teachers communicate in advance in two countries and find a pen friend for each student from abroad. Students then email each other weekly. In his letters, they talk about their daily life, School, family, hobbies, and also ask each other questions about the culture of their country. For example, our student asked a foreign friend: "What do students call a teacher in your schools? By name or by Mr/Mrs?" - a foreign student may ask our student about their national cuisine or holidays. Every week, the teacher can give a little direction and suggest a topic for discussion (for example: "write to each other on the topic of sports and games this week"). After a while, students can arrange a video meeting via Skype, Zoom and strengthen their acquaintance.

In the course of this virtual exchange, students use language in the context of natural communication, that is, language learning serves a specific purpose – understanding with a real person. Students learn not only to immerse themselves in the language environment, but also to relate to each other's culture: what topics can be discussed when communicating with a representative of a foreign culture, what things cannot be said, how to maintain politeness-they experience such subtle points in practice. For example, some Kazakh students may initially translate "you" to their English-speaking friends, regardless of age, and over time, realizing that this form sounds formal to foreigners, they get used to the informal "you" style of communication. In the same way, it is not surprising that a foreign student learns to take into account the etiquette of respect for elders in our country. By discussing with virtual friends, both parties are accustomed to mutual respect and understanding, differentiating the characteristics of their cultures in the mind. This is the ultimate goal of forming a multicultural personality.

There are many other types of virtual exchange organization. For example, there are such types as participation in international educational projects (teleconference, online conference, joint video filming, etc.), establishing contacts with a foreign School (sister school) and constant cooperation with teachers, preparing reports on virtual trips abroad (with the help of Google Earth, online museum tours). It is important for the student to gain experience in direct communication with representatives of other cultures. Such experience is of great educational value: such qualities as tolerance, openness, empathy are formed in students.

The ability to communicate with different parts of the world via the internet is a huge advantage that belongs to modern learners. Therefore, the maximum use of this resource in English lessons, creating conditions for free admission of students to the wider world outside the classroom is one of the requirements of the time.

Conclusion

In conclusion, the formation of socio-cultural competence in the senior grades of a comprehensive school is one of the most pressing tasks in teaching a modern foreign language. Only when a student perceives a foreign language not only as language material, but as the key to getting to know another people, another environment through that language, his language skills develop deeper and more consciously. In this sense, the integrated use of internet resources in the classroom can be a very effective tool. With the help of information and communication technologies, the teacher can create a virtual socio-cultural environment in the classroom, and immersion in a virtual environment is the most effective way to develop students' socio-cultural competence. Reasonable use of computer technologies increases students' motivation for learning, strengthens self-confidence, and creates the most comfortable interactive atmosphere. At the same time, the educational material through the internet creates an opportunity to adapt the content to the personal interests of the student, to independent search and creativity.

The methods analyzed in the article (authentic video viewing, web quest, blog, virtual exchange) offer the teacher specific ways to implement socio-cultural education in the classroom process and outside the classroom. Of course, the use of any new method requires training from the teacher: there are such works as selecting the quality of internet materials, checking compliance with educational goals, ensuring technical usability. However, the return on such work will be great. Students feel the real language environment and adapt to free communication in a foreign language. The main thing is that the foundation is laid for the formation of an educated and cultured person with a global vision of respect for another culture.

Thus, the use of internet resources in English lessons plays a huge role in educating high school students as multilingual citizens who can participate in the dialogue of cultures in accordance with the requirements of the time. The teaching community can enrich the content of teaching, combining new technologies and traditional education. We conclude that the proposed methodological approaches have proven their effectiveness in improving the socio-cultural competence of students in practice, so they can be widely included in the educational process.

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Perceptions and Behavioral Responses to True and False News: A Survey Study

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Introduction

In the digital information age, the rapid advancement of internet communication technologies and the popularization of intelligent tools have expedited the dissemination of information, while also fostering a breeding ground for the spread of false news. Characterized by rapid transmission, strong concealment and wide-ranging influence, false news not only distorts the public's accurate cognition of events, but also erodes the credibility of information dissemination channels and even poses potential threats to social order and stability. Meanwhile, the rise of artificial intelligence (AI) technology has emerged as a double-edged sword in the field of information communication: on one hand, it offers innovative tools and methods for information verification and false news identification, empowering both the public and professional institutions to screen information more efficiently; on the other hand, it has spawned new forms of false information such as deep fake content, which are more realistic and deceptive, bringing unprecedented challenges to the governance of true and false news.¹

Against this backdrop, the public's cognition level and response behaviors toward true and false news have become core research topics for understanding the current state of information dissemination and optimizing false news governance strategies. To explore the public's practical attitudes, behavioral tendencies and decision-making logic when facing true and false news, as well as their cognition of AI-related risks and human-machine collaboration models in the news field, this survey was conducted. By collecting and analyzing questionnaire data from respondents with different age and professional backgrounds, the report sorts out the public's information verification habits, risk perception of AI in the news industry and cognitive characteristics of human-machine collaboration in information identification. It further summarizes the existing problems in the public's information judgment and response, and puts forward targeted thinking and suggestions for subsequent fake news prevention and control. This research is expected to provide a micro perspective and basic empirical reference for improving the public's social media literacy, advancing technical prevention and control means, and constructing a scientific, efficient and multi-dimensional false news governance system.²

Methods

This study adopted a questionnaire survey method to collect primary data on the public's cognition and response behaviors toward true and false news, as well as their perception of AI-related risks in the news field. A total of 8 valid questionnaires were recovered after the survey, and the respondent group was structured to cover different age and professional backgrounds for basic stratification: in terms of age, the sample was equally divided into the 18-30 age group and the over-31 age group (4 respondents in each group), achieving a balanced distribution of young and middle-aged groups; in terms of professional background, 75% of respondents (6 people) majored in humanities and social sciences, and 25% (2 people) in science and engineering, reflecting the characteristics of higher information sensitivity among social science background groups. The questionnaire set questions involving information verification methods, AI risk cognition in the news field and recognition of human-machine collaboration models, with multiple-choice and single-choice question types combined, and allowed multiple selections for risk cognition questions to fully capture the respondents' subjective perceptions and behavioral

tendencies. After data collection, descriptive statistical analysis was used to sort out and summarize the response results, and in-depth discussion was conducted based on the statistical data to explore the internal characteristics and existing problems of the public's cognition and behaviors.³

Results

Information Verification and Response Behaviors to True and False News

The survey results show significant differentiation in the public's choice of information verification and response methods when facing true and false news:

Official media as the primary verification choice: 50% of respondents (4 people) chose to verify the authenticity of news through official media, which reflects the public's high level of trust in authoritative information sources and the formation of basic authoritative source judgment awareness.

High reliance on AI tools for verification: 25% of respondents (2 people) prioritized consulting AI tools (e.g., ChatGPT) for information verification, indicating that AI has gradually become an important auxiliary tool for the public in information judgment in the digital age.

Weak awareness of multi-source comparison verification: Only 12.5% of respondents (1 person) would take the initiative to compare multiple information sources to verify news authenticity, showing a serious deficiency in the public's multi-dimensional information screening awareness.

Existence of passive response behavior: 12.5% of respondents (1 person) chose to ignore false news directly when encountering it, reflecting the presence of passive avoidance tendencies in individual responses to false news.

Public Cognition of AI Risks in the News Field

For AI-related risks in the news field (multiple choices allowed), respondents' cognitive focus showed a high degree of concentration, with the risk perception distribution as follows:

Deepfake content creation as the primary risk: 87.5% of respondents (7 people) regarded AI's creation of deepfake content as the main risk, which is the most concerned AI risk point among the surveyed groups.

Concern about occupational displacement of journalists: 50% of respondents (4 people) were worried about AI replacing journalists' positions, reflecting the public's attention to the impact of AI on the professional structure of the news industry.

Moderate attention to algorithmic bias: 25% of respondents (2 people) paid attention to the risk of algorithmic bias in AI's news production and dissemination, indicating that the public's cognition of AI's technical fairness is relatively limited.

Low attention to the amplification of false information spread: Only 12.5% of respondents (1 person) noticed the risk that AI amplifies the spread of false information, showing the public's insufficient cognition of AI's role in the communication chain of false news.

Public Recognition of Human-Machine Collaboration in Information Identification

In terms of the cognitive attitude toward human-machine collaboration models for false news identification and verification, 87.5% of respondents recognized and accepted this model, reflecting that the surveyed public has a rational and mature understanding of the complementary relationship between AI technology and human judgment in information verification, and does not show extreme reliance on technology or rejection of technical tools.

Discussion

Positive Characteristics of Public Cognition and Response Behaviors

Established trust in authoritative information sources and basic judgment ability: The fact that 50% of respondents prioritize official/authoritative media for news verification indicates that the public has formed a basic ability to judge reliable information sources in the complex information environment. This trust in authoritative sources is an important foundation for

resisting false news, which can effectively reduce the probability of the public being misled by untrue information and lay a good individual cognitive foundation for social-level false news governance.

Rational cognition of human-machine collaboration and adaptive use of AI tools: The high recognition rate (87.5%) of the human-machine collaboration model for information verification, coupled with the 25% of respondents who use AI tools as the primary verification method, shows that the public has a mature understanding of the positioning of AI technology in information screening. The public can recognize the advantages of AI in efficient information processing and also understand the necessity of human judgment in identifying the authenticity of complex information, reflecting an adaptive attitude toward digital technical tools.

High vigilance against core AI risks in the news field: The vast majority of respondents (87.5%) pay close attention to the risk of AI creating deepfake content, which shows that the public has a clear perception of the most prominent and deceptive AI risk in the current news field. This high vigilance can make the public more cautious when facing information generated or edited by AI, reducing the possibility of being deceived by deepfake false news, and is a positive performance of the public's AI risk perception.

Prominent Problems in Public Cognition and Response Behaviors

Serious deficiency in multi-source verification awareness: The extremely low proportion (12.5%) of respondents who take the initiative to conduct multi-source information comparison is a prominent problem in the current public's information verification behavior. In the era of information diversification, a single information source often has limitations or biases, and the lack of multi-source comparison awareness makes the public easy to fall into the cognitive trap of one-sided information, which not only affects the accuracy of individual information judgment, but also provides space for the spread of single-source false news.⁴

Insufficient cognition of the whole chain of AI risks in the news field: The public's cognition of AI risks in the news field is highly concentrated on deepfake content creation, while the attention to algorithmic bias and AI's amplification of false information spread is extremely low (25% and 12.5% respectively). This one-sided risk cognition means that the public ignores the hidden risks of AI in the news production and dissemination process: algorithmic bias may lead to the biased dissemination of news information and the solidification of public cognitive stereotypes, while AI's technical advantages in information dissemination can accelerate the spread of false news on a large scale, and the lack of cognition of these risks will make the public unable to effectively guard against such hidden dangers.⁵

Presence of passive response tendencies to false news: The 12.5% of respondents who choose to ignore false news directly reflect the existence of passive avoidance in individual responses to false news. This passive behavior not only fails to curb the spread of false news, but also may make the false information continue to spread in the social network, and even form a larger-scale public opinion impact in the long run. The lack of active verification and refutation awareness makes individual behavior unable to form an effective joint force for social-level false news governance.⁶

Limitations of the Survey

This survey has certain limitations that affect the generalization of the conclusions, mainly reflected in the following aspects: first, the **small sample size**—only 8 valid questionnaires were collected, and the small sample makes the research results lack sufficient representativeness, and the conclusions cannot be directly extended to the whole society; second, **unbalanced professional backgrounds**—the sample is overrepresented by humanities and social sciences majors (75%), while the perspectives of science and engineering majors are insufficient, and the differences in information cognition and behavior characteristics among different professional groups cannot be fully reflected; third, **limited research scenarios**—only two types of fake news

scenarios were set in the questionnaire, with insufficient coverage of the diverse forms of false news in reality, and the research results cannot reflect the public's response behaviors in different false news scenarios; fourth, **missing regional information**—the survey did not collect the regional information of the respondents, making it impossible to analyze the differences in the public's cognition and response behaviors toward false news in different regions due to factors such as economic development and information popularization.

Conclusion

This survey, through the analysis of questionnaire data from respondents with different age and professional backgrounds, reveals the basic characteristics of the public's cognition and response behaviors toward true and false news, as well as their perception of AI-related risks in the news field. The vast majority of the public have a high vigilance against the most prominent AI risk in the news field—deepfake content creation, which shows that the public's AI risk perception has captured the core risk points in the current digital information era, laying a good subjective foundation for guarding against AI-generated false news. These positive characteristics fully reflect that the public has adapted to the development of digital information technology to a certain extent, and has formed basic information judgment and risk awareness in the complex information environment, which are important internal driving forces for constructing a social-level false news governance system.⁷

In addition, in view of the limitations of this survey, follow-up research should expand the sample size, balance the professional, age and regional distribution of respondents, and set more diverse false news scenarios to make the research results more representative and practical. At the same time, follow-up research can also conduct in-depth exploration on the differences in cognition and response behaviors toward false news among different groups, and put forward targeted governance suggestions according to the characteristics of different groups, so as to continuously optimize the false news governance system and adapt to the new challenges brought by the development of digital information technology and AI technology to the field of information dissemination.⁸

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Chemical Sciences

SYNTHESIS OF ION-EXCHANGE RESINS BASED ON PHENOL-FORMALDEHYDE OLIGOMERS AND THEIR APPLICATION AREAS

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Summary. Sulfated compounds based on phenol–formaldehyde oligomers represent an important class of functional polymer materials with wide industrial applicability. In this study, the preparation of sulfated phenol–formaldehyde oligomers through chemical modification is considered, along with the changes induced in their physicochemical properties. The introduction of sulfate or sulfo groups into the oligomer structure significantly enhances water solubility, surface activity, and ionogenic character, transforming initially hydrophobic materials into multifunctional additives.

The sulfation process, typically carried out using strong sulfating agents such as sulfuric acid, chlorosulfonic acid, or oleum, proceeds via electrophilic substitution on activated phenolic rings. Reaction conditions strongly influence the degree of sulfation and, consequently, the functional performance of the resulting products. Sulfated phenol–formaldehyde oligomers exhibit high efficiency as dispersants, emulsifiers, and stabilizers, while maintaining stability even in electrolyte-containing environments. Owing to these properties, they find extensive application in the oil and gas industry, construction materials, chemical and petrochemical processes, textile and paper production, as well as environmental technologies such as wastewater treatment. The results demonstrate that sulfation is an effective approach for expanding the application potential of phenol–formaldehyde oligomers and highlights their promise for further research and industrial development.

Keywords: Phenol–formaldehyde oligomers; sulfation; functional polymers; surface-active agents; dispersants; industrial applications.

In modern chemistry and materials science, the development of polymeric materials with advanced functional properties has become one of the key directions of scientific research and industrial innovation. The continuous growth of industrial production, increasing environmental requirements, and the need for materials with improved physicochemical characteristics have stimulated extensive studies on the modification of traditional polymer systems. In this context, phenol–formaldehyde oligomers represent one of the most widely used classes of synthetic polymers due to their high mechanical strength, thermal stability, chemical resistance, and relatively simple synthesis process. These oligomers have been successfully applied in various industrial sectors, including adhesives, coatings, composite materials, and ion-exchange resins. Nevertheless, despite their valuable properties, the practical application of conventional phenol–formaldehyde oligomers is sometimes limited by their hydrophobic nature and insufficient

solubility in aqueous environments. For this reason, the functional modification of phenol–formaldehyde oligomers has become an important research topic aimed at improving their physicochemical characteristics and expanding their fields of application. One of the most effective approaches for enhancing the performance of these oligomers is sulfation, which significantly alters their structural and functional properties and creates new opportunities for their practical utilization [1].

The introduction of sulfate groups into the molecular structure of phenol–formaldehyde oligomers leads to a substantial transformation of their physicochemical behavior. As a result of sulfation, the originally hydrophobic polymer structure becomes hydrophilic and water-soluble, which significantly increases its compatibility with aqueous systems. In addition, the presence of sulfate groups imparts ionogenic and surface-active properties to the modified oligomers. These changes considerably enhance their ability to interact with various solid and liquid phases, making them effective components in numerous technological processes. The formation of anionic functional groups also improves the electrostatic stabilization of colloidal systems and increases the dispersing capability of the material. Consequently, sulfated phenol–formaldehyde oligomers acquire considerable practical importance in different branches of industry, particularly in oil and gas extraction processes, construction materials technology, and chemical manufacturing, where stable dispersing and emulsifying agents are required for efficient technological operations [2].

Phenol–formaldehyde oligomers are generally synthesized through a condensation reaction between phenol and formaldehyde under controlled reaction conditions. During this process, formaldehyde molecules react with the aromatic rings of phenol, resulting in the formation of methylene bridges that connect individual phenolic units into a polymeric network. This condensation reaction leads to the formation of oligomeric structures that contain aromatic cores linked by $-\text{CH}_2-$ groups, as well as a significant number of reactive hydroxyl groups located on the phenolic rings. The presence of these hydroxyl groups plays a crucial role in determining the chemical reactivity of phenol–formaldehyde oligomers, since they serve as active sites for further chemical transformations and functional modifications. As a result, phenol–formaldehyde oligomers provide a versatile platform for the introduction of various functional groups that can significantly alter their physicochemical and technological properties [3].

However, in their original form, phenol–formaldehyde oligomers usually possess a predominantly hydrophobic character and exhibit limited solubility in water. This characteristic restricts their use in many industrial processes where water-based systems are required. For example, in oilfield technologies, construction chemistry, and dispersant production, the ability of a polymer to dissolve in water and stabilize heterogeneous systems is essential for achieving high process efficiency. Therefore, researchers have focused considerable attention on developing chemical modification techniques that can improve the hydrophilicity and surface activity of phenol–formaldehyde oligomers. Among these modification methods, sulfation has proven to be particularly effective because it introduces strongly polar functional groups into the polymer structure. As a result, sulfated oligomers acquire pronounced hydrophilic properties and significantly improved surface activity, which greatly broadens their industrial applicability [4].

The sulfation of phenol–formaldehyde oligomers is a chemical modification process that involves the introduction of sulfate ($-\text{OSO}_3\text{H}$) or sulfo ($-\text{SO}_3\text{H}$) groups into the molecular structure of the oligomer. This process is usually carried out in the presence of strong sulfating agents capable of reacting with aromatic compounds. The most frequently used reagents for this purpose include concentrated sulfuric acid, chlorosulfonic acid, and oleum, which are known for their strong electrophilic properties. During the sulfation reaction, the sulfating agent acts as an electrophile and attacks the electron-rich aromatic ring of the phenolic structure. The hydroxyl groups present in the phenolic ring have an activating effect that increases the electron density of the aromatic system and facilitates electrophilic substitution reactions. As a result, sulfate or sulfo

groups are introduced mainly into the activated positions of the phenolic ring, forming sulfated derivatives of phenol–formaldehyde oligomers. The extent and efficiency of the sulfation process depend strongly on reaction parameters such as temperature, reaction time, reagent concentration, and the ratio of reactants. Mild reaction conditions generally lead to the formation of products with a relatively low degree of sulfation, whereas more intensive conditions allow the synthesis of oligomers with a higher concentration of ionogenic functional groups.

The compounds obtained as a result of sulfation possess physicochemical properties that differ fundamentally from those of the initial phenol–formaldehyde oligomers. One of the most significant changes is their enhanced solubility in water, which enables the formation of stable aqueous and colloidal systems. The presence of sulfate groups gives the polymer an anionic character, resulting in strong electrostatic interactions with dispersed particles and interfaces between immiscible phases. This property considerably improves the surface activity of the material and allows it to function effectively as a dispersing agent or emulsifier. In practical applications, sulfated phenol–formaldehyde oligomers facilitate the uniform distribution of solid particles or liquid droplets within a continuous medium, thereby preventing aggregation and phase separation. As a consequence, the stability of heterogeneous systems is maintained over long periods, which is essential for many industrial processes, including drilling fluid preparation, cement additives, and chemical formulations. Another important advantage of sulfated phenol–formaldehyde oligomers is their ability to retain functional stability even in environments containing significant concentrations of electrolytes. In many industrial processes, especially in the oil and gas sector, chemical additives must operate under conditions characterized by high salinity, elevated temperatures, and complex chemical compositions. Many conventional dispersants and surfactants lose their efficiency in such environments due to precipitation or reduced surface activity. However, sulfated phenol–formaldehyde oligomers demonstrate a high degree of resistance to electrolyte effects and maintain their dispersing and stabilizing properties under challenging conditions. This characteristic makes them particularly valuable for applications in drilling fluids, enhanced oil recovery technologies, and cementing operations, where chemical stability and performance reliability are critically important [5-7].

In addition to their chemical and technological significance, sulfated phenol–formaldehyde oligomers also contribute to improving the efficiency and sustainability of industrial processes. By enhancing the dispersion and stabilization of materials, they help reduce the consumption of raw materials and improve the overall quality of final products. Their multifunctional nature allows them to be used simultaneously as dispersants, emulsifiers, and stabilizing agents, which simplifies technological processes and reduces the number of required additives. Consequently, the development and optimization of sulfated phenol–formaldehyde oligomers continue to attract significant scientific interest, as they represent promising materials for modern industrial technologies and advanced functional polymer systems.

Overall, the diagram illustrates that the woodworking industry occupies the dominant position in the production structure of phenol–formaldehyde-based materials, reflecting the extensive use of these polymers in wood adhesives, laminates, and engineered wood products. At the same time, other industrial sectors such as construction, chemical production, and oil-and-gas technologies also contribute to the overall production distribution, although their shares are relatively smaller. Nevertheless, these sectors collectively represent a diversified and expanding field of application for modified phenol–formaldehyde materials, especially for those obtained through sulfation and other functional modification techniques [8-9].

Sulfated phenol–formaldehyde oligomers are extensively utilized in the oil and gas industry, particularly in drilling, well completion, and reservoir treatment processes. In drilling operations, these compounds are incorporated into drilling fluids as dispersants and rheology modifiers. Their presence significantly improves the flow characteristics of drilling mud by reducing viscosity

fluctuations and stabilizing the dispersion of solid particles such as clay, barite, and rock cuttings. By preventing the aggregation and sedimentation of these particles, sulfated phenol–formaldehyde oligomers help maintain the homogeneity and stability of the drilling fluid system even under high-pressure and high-temperature conditions. This ensures efficient removal of drill cuttings from the wellbore and prevents operational problems such as pipe sticking or blockage of circulation channels. In addition, during reservoir treatment and enhanced oil recovery operations, these compounds promote the dispersion of fine rock particles and prevent pore clogging within the reservoir formation. As a result, the permeability of the reservoir rock can be improved, which facilitates the movement of hydrocarbons and contributes to increased oil and gas recovery efficiency [10].

In the construction materials industry, sulfated phenol–formaldehyde oligomers are widely applied as high-performance plasticizing and dispersing additives in cement-based systems such as concrete and cement mortars. When introduced into concrete mixtures, these compounds significantly improve the workability and fluidity of the mixture without requiring additional water. This effect is achieved because the anionic sulfate groups adsorb onto the surface of cement particles and create electrostatic repulsion between them, preventing agglomeration and ensuring a more uniform dispersion of particles throughout the mixture. As a result, the water demand of the system is reduced while the mobility of the concrete mixture is increased. Lower water content leads to the formation of a denser microstructure during cement hydration, which ultimately enhances the compressive strength, durability, and resistance to environmental degradation of the hardened concrete. Furthermore, the use of such additives improves the long-term performance of construction materials by reducing porosity, increasing frost resistance, and improving resistance to chemical corrosion, making sulfated phenol–formaldehyde oligomers valuable components in modern construction technologies [11].

In the chemical and petrochemical industries, sulfated phenol–formaldehyde oligomers are widely employed as emulsifying and stabilizing agents in the preparation of emulsions, suspensions, and latex systems. Their amphiphilic structure, which contains both hydrophobic aromatic fragments and hydrophilic sulfate groups, enables them to effectively reduce interfacial tension between immiscible phases such as oil and water. This property allows the formation of stable emulsions that remain homogeneous over long periods without phase separation. In industrial processes, these emulsions are essential for the production of synthetic rubber, polymer latexes, paints, coatings, and other chemical products. Additionally, when incorporated into polymer composite materials, sulfated phenol–formaldehyde oligomers act as stabilizers that enhance the structural integrity and durability of the composite system. By improving the compatibility between different components within the composite matrix, they contribute to improved mechanical performance, thermal stability, and resistance to environmental degradation. Consequently, these compounds play an important role in increasing the service life and reliability of materials used in chemical and petrochemical technologies [12].

Sulfated phenol–formaldehyde oligomers also find significant application in the textile and paper industries due to their excellent dispersing and surface-active properties. In textile processing, they are used primarily during dyeing and finishing operations, where they serve as dispersing agents that facilitate the uniform distribution of dye molecules in aqueous dye baths. By preventing the aggregation of dye particles, these oligomers promote better penetration of dyes into the fiber structure, leading to more uniform coloration and improved color fastness of the finished textile products. Moreover, their stabilizing effect ensures consistent dyeing quality across different batches of fabric. In the paper industry, sulfated phenol–formaldehyde oligomers improve the interaction between cellulose fibers during the paper formation process. Their dispersing action enhances the uniform distribution of pulp fibers within the suspension and promotes stronger bonding between fibers in the paper sheet. As a result, the produced paper

exhibits improved mechanical properties, such as increased tensile strength, better tear resistance, and enhanced structural uniformity, which are essential qualities for high-quality paper products [13].

From an environmental perspective, sulfated phenol–formaldehyde oligomers demonstrate considerable potential in water purification and wastewater treatment technologies. Due to the presence of negatively charged sulfate groups in their molecular structure, these compounds are capable of interacting with positively charged metal ions and other pollutants present in contaminated water. This interaction enables the adsorption and removal of harmful substances such as heavy metal ions, including lead, cadmium, and copper, as well as certain organic contaminants. In wastewater treatment systems, sulfated phenol–formaldehyde oligomers can function as effective flocculating or adsorbing agents that facilitate the aggregation and precipitation of pollutants, making their subsequent removal easier. By reducing the concentration of toxic substances in water, these compounds contribute to improving water quality and protecting aquatic ecosystems. Consequently, their application in environmental technologies highlights their importance not only as industrial additives but also as functional materials that support sustainable environmental protection strategies and resource management practices.

Phenol–formaldehyde oligomers belong to one of the earliest and most thoroughly investigated classes of synthetic polymers in modern polymer chemistry. Since the pioneering work of Leo Baekeland in the early twentieth century, phenol–formaldehyde resins have played a fundamental role in the development of synthetic polymeric materials. Their discovery marked the beginning of the era of industrial plastics and opened new possibilities for the production of chemically resistant and mechanically durable materials. Over the decades, these polymers have been extensively used in various industrial sectors due to their outstanding properties, including high mechanical strength, excellent thermal stability, resistance to aggressive chemical environments, and structural versatility. In addition, the aromatic structure of phenol–formaldehyde polymers allows them to undergo a wide range of chemical modifications, making them suitable precursors for advanced functional materials. One of the most promising modern research directions in this field involves the use of phenol–formaldehyde oligomers as polymer matrices for the synthesis of ion-exchange resins. These resins represent a class of functional polymeric materials capable of exchanging ions between the solid polymer phase and surrounding liquid media. Because of this property, ion-exchange resins are widely utilized in numerous technological processes, including water purification, hydrometallurgy, chemical separation technologies, and environmental remediation systems [14-15].

The synthesis of ion-exchange resins based on phenol–formaldehyde oligomers begins with the polycondensation reaction between phenol and formaldehyde, which represents the fundamental chemical process underlying the formation of phenolic polymer structures. This reaction is typically carried out in the presence of either acidic or alkaline catalysts, depending on the desired type of oligomeric product. During the polycondensation process, formaldehyde molecules react with the activated positions of phenol molecules, leading to the formation of methylene bridges that link individual phenolic units into oligomeric chains. As the reaction proceeds, these chains grow in length and gradually form more complex polymeric structures. The physicochemical characteristics of the resulting oligomers are strongly influenced by several reaction parameters, including temperature, catalyst type, reaction duration, and the molar ratio of phenol to formaldehyde. When the reaction occurs under alkaline conditions in the presence of an excess amount of formaldehyde, resol-type oligomers are formed. These oligomers contain reactive methylol groups that allow them to undergo further condensation and cross-linking reactions. In contrast, when the polycondensation reaction takes place under acidic conditions with an excess of phenol, novolac-type oligomers are obtained. Novolac oligomers generally

require additional curing agents to form cross-linked polymer networks. Both resol and novolac oligomers serve as important intermediates for the production of phenol–formaldehyde-based ion-exchange resins and other functional polymer materials [16].

The next essential stage in the preparation of ion-exchange resins involves the introduction of ionogenic functional groups into the polymer structure. These functional groups are responsible for the ion-exchange capacity of the material and determine its chemical selectivity toward different ionic species. The incorporation of such groups transforms the polymer from an inert structural material into an active ion-exchange medium capable of participating in reversible ion-exchange reactions. One of the most widely used chemical modification methods is the sulfonation of the phenol–formaldehyde polymer network. During this process, sulfonic acid groups ($-\text{SO}_3\text{H}$) are introduced into the aromatic rings of the polymer matrix through electrophilic substitution reactions. The resulting materials function as strong cation-exchange resins, capable of exchanging hydrogen ions with various metal cations present in aqueous solutions. These cation-exchange resins are particularly effective in removing ions such as calcium, magnesium, sodium, and heavy metals from aqueous systems. Alternatively, the introduction of amino groups or quaternary ammonium groups into the polymer structure leads to the formation of anion-exchange resins. These materials possess positively charged functional groups that can bind and exchange negatively charged ions, including chloride, nitrate, sulfate, and phosphate ions. Through the careful selection of functional groups and synthesis conditions, ion-exchange resins with tailored selectivity and capacity can be produced for specific technological applications.

To ensure that the ion-exchange material possesses sufficient mechanical stability and operational durability, the oligomeric structure is usually subjected to cross-linking reactions that result in the formation of a three-dimensional polymer network. Cross-linking plays a crucial role in determining the physical and chemical stability of the resin during practical use. The formation of a highly cross-linked structure enhances the mechanical strength of the material and prevents excessive swelling or dissolution in aqueous environments. In addition, cross-linking significantly increases the chemical resistance of the polymer matrix, allowing it to withstand exposure to acidic, alkaline, and oxidative conditions commonly encountered in industrial processes. Another important consequence of cross-linking is the development of a porous internal structure within the resin particles. The presence of interconnected pores facilitates the diffusion of ions from the surrounding solution into the interior of the polymer matrix, where ion-exchange reactions take place. This porous morphology improves the kinetics of ion exchange and enhances the overall efficiency of the material in separation and purification processes.

Phenol–formaldehyde-based ion-exchange resins possess a number of advantageous physicochemical properties that make them highly attractive for industrial and technological applications. One of their most important characteristics is their high thermal stability, which allows them to maintain structural integrity and functional performance at elevated temperatures. In addition, these resins demonstrate strong resistance to both acidic and alkaline environments, enabling their use in chemically aggressive media. The aromatic nature of the phenol–formaldehyde polymer framework contributes to the rigidity and durability of the material, ensuring that it retains its mechanical strength even after prolonged operational use. Furthermore, the highly cross-linked structure of these polymers provides excellent resistance to oxidative degradation and mechanical wear. As a result, ion-exchange resins based on phenol–formaldehyde matrices exhibit long service life and can withstand multiple regeneration cycles without significant loss of performance, making them economically advantageous for large-scale industrial operations.

One of the most important and widely recognized application areas of phenol–formaldehyde-based ion-exchange resins is water purification and water treatment technology. In domestic and industrial water softening systems, these resins are used to remove hardness ions such as calcium

(Ca^{2+}) and magnesium (Mg^{2+}), which are responsible for scale formation and reduced efficiency in water-using equipment. By exchanging these ions with hydrogen or sodium ions, ion-exchange resins effectively reduce water hardness and improve water quality. In municipal and industrial wastewater treatment facilities, ion-exchange resins are also used to remove toxic heavy metal ions such as lead, cadmium, mercury, and chromium from contaminated water streams. Their ability to selectively bind specific ionic species makes them extremely valuable in advanced environmental protection technologies. Through the removal of hazardous substances from water resources, these materials contribute significantly to reducing environmental pollution and protecting aquatic ecosystems. Consequently, phenol–formaldehyde-based ion-exchange resins continue to play a critical role in modern water treatment systems and sustainable environmental management strategies [17-20].

In addition to their extensive use in water purification technologies, phenol–formaldehyde-based ion-exchange resins also play a significant role in the chemical and petrochemical industries. These materials are widely utilized in various catalytic and separation processes where the selective exchange of ions is required to achieve high product purity and process efficiency. In many chemical production systems, ion-exchange resins function as heterogeneous catalysts that facilitate acid–base reactions, esterification processes, and hydrolysis reactions. Their solid polymeric structure allows them to serve as stable catalytic supports while maintaining high reactivity and selectivity. Furthermore, in petrochemical processing, these resins are used for the purification of intermediate chemical products and for the removal of ionic impurities that may interfere with subsequent technological steps. Another important application area is hydrometallurgy, where ion-exchange resins are used for the recovery, concentration, and separation of valuable metals from aqueous solutions obtained during ore processing. Through selective ion-exchange mechanisms, these materials enable the extraction of economically important metals such as copper, nickel, uranium, and various rare earth elements. Their high chemical stability, resistance to aggressive media, and strong affinity toward specific metal ions allow efficient metal recovery even in highly complex and multicomponent chemical environments, making them indispensable tools in modern metallurgical technologies.

Ion-exchange resins derived from phenol–formaldehyde oligomers also find widespread application in analytical chemistry and laboratory-based separation techniques. One of the most important analytical methods in which these materials are used is ion-exchange chromatography, a powerful technique for the separation, purification, and quantitative analysis of ionic substances. In chromatographic systems, ion-exchange resins serve as stationary phases capable of selectively binding target ions while allowing other components of the mixture to pass through the column. This property enables the precise separation of complex chemical mixtures and contributes to highly accurate analytical measurements. In addition to their role in laboratory analysis, these resins are also widely applied in the pharmaceutical and food industries. In pharmaceutical manufacturing, ion-exchange resins are used to purify active pharmaceutical ingredients by removing unwanted ionic impurities, by-products, or trace metal contaminants that may affect the safety and effectiveness of medicinal products. Similarly, in the food industry, these materials are employed in processes such as sugar purification, removal of undesirable colorants, and elimination of trace contaminants from food-grade solutions. By improving the purity and stability of processed substances, ion-exchange resins significantly contribute to maintaining high product quality and safety standards in these industries.

In recent years, scientific research has increasingly focused on improving the physicochemical and functional properties of phenol–formaldehyde-based ion-exchange resins through advanced chemical modification techniques. Researchers are actively exploring new synthesis strategies aimed at enhancing the ion-exchange capacity, selectivity, and operational stability of these materials. One of the main directions of such research involves the introduction of additional

functional groups into the polymer structure, which can increase the density of active ion-exchange sites and improve the resin's affinity toward specific target ions. For example, the incorporation of specialized chelating groups can significantly enhance the selective binding of heavy metal ions, while the modification of polymer morphology can improve ion diffusion and exchange kinetics. At the same time, scientists are also investigating environmentally friendly synthesis routes that reduce the use of hazardous reagents and minimize the environmental impact of polymer production. Advances in polymer chemistry, nanotechnology, and materials science continue to expand the range of possible modifications and applications of these materials. As a result, phenol–formaldehyde-based ion-exchange resins are increasingly being considered as promising materials for innovative industrial technologies and sustainable environmental solutions.

In conclusion, ion-exchange resins synthesized from phenol–formaldehyde oligomers represent an important class of functional polymeric materials with broad industrial significance and technological relevance. Their synthesis involves a series of carefully controlled chemical processes, including polymerization, cross-linking, and functional group incorporation, which together create materials capable of efficiently exchanging ions under various chemical and environmental conditions. The combination of high chemical stability, strong mechanical durability, and adaptable functional properties makes these resins highly suitable for a wide range of industrial applications. They are widely used in water treatment systems, environmental protection technologies, hydrometallurgical metal recovery processes, chemical production operations, and analytical laboratory techniques. The versatility and reliability of phenol–formaldehyde-based ion-exchange resins ensure their continued importance in modern industrial practice. As scientific research and technological development in polymer chemistry continue to progress, these materials are expected to play an increasingly significant role in the advancement of sustainable industrial processes and environmentally responsible technologies [21–24].

The continuous development of polymer science has created new opportunities for improving the functional characteristics of phenol–formaldehyde oligomer derivatives. In recent years, particular attention has been devoted to the design of multifunctional polymer systems that combine dispersing, catalytic, and ion-exchange properties within a single material. Sulfated phenol–formaldehyde oligomers represent a promising platform for such multifunctional systems because their chemical structure allows the introduction of various functional groups capable of interacting with different chemical species. Through careful molecular design and controlled synthesis conditions, it is possible to tailor the surface activity, ion-exchange capacity, and adsorption properties of these materials for specific industrial tasks.

Another important direction in the development of phenol–formaldehyde-based functional materials is the investigation of their physicochemical behavior in complex industrial environments. In practical technological processes, polymer additives are often exposed to elevated temperatures, high salinity, aggressive chemical media, and mechanical stresses. Therefore, researchers have focused on studying the thermal stability, chemical resistance, and long-term durability of sulfated phenol–formaldehyde oligomers under such conditions. Experimental studies have shown that the aromatic polymer backbone of phenol–formaldehyde systems provides significant structural rigidity, which contributes to their resistance against thermal degradation and oxidative processes. This stability is particularly valuable in industrial systems such as drilling fluids, cement mixtures, and chemical reactors, where operating conditions are often extreme.

Another promising research direction involves the use of sulfated phenol–formaldehyde oligomers as functional additives in advanced fluid systems. In particular, these materials can play an important role in stabilizing colloidal dispersions, improving suspension stability, and controlling particle aggregation in complex fluid media. Their strong anionic character allows them

to interact effectively with positively charged particles, preventing coagulation and sedimentation. This property is especially valuable in industries such as oil drilling, ceramic production, pigment dispersion, and mineral processing, where maintaining stable suspensions is critical for efficient process operation [25-30].

Furthermore, the ability of sulfated phenol–formaldehyde oligomers to interact with metal ions and charged particles makes them suitable candidates for advanced adsorption technologies. Their ionogenic functional groups can bind heavy metal ions, dyes, and other contaminants from aqueous solutions through electrostatic interactions and coordination mechanisms. This property provides opportunities for developing efficient materials for wastewater treatment, environmental remediation, and resource recovery processes. In particular, these materials may contribute to the removal of toxic pollutants from industrial effluents and help protect natural water resources from contamination [31].

The rapid development of analytical techniques and characterization methods has also contributed to a deeper understanding of the structure and performance of phenol–formaldehyde-based functional materials. Modern instrumental methods such as infrared spectroscopy, nuclear magnetic resonance spectroscopy, scanning electron microscopy, and thermal analysis allow researchers to investigate the molecular structure, surface morphology, and thermal stability of synthesized polymers in detail. These analytical techniques provide valuable information that helps optimize synthesis parameters and improve the overall performance of the materials. As a result, more efficient and precisely designed phenol–formaldehyde-based functional systems can be developed for specific industrial applications [32].

Overall, the continuous progress in polymer chemistry, materials science, and industrial technology ensures that phenol–formaldehyde-derived functional materials remain highly relevant in modern scientific research and technological development. Their unique combination of chemical stability, structural adaptability, and functional versatility allows them to serve as effective components in numerous industrial processes. With ongoing advancements in synthesis techniques, molecular design, and environmental technologies, sulfated phenol–formaldehyde oligomers and related polymer systems are expected to maintain an important role in the development of innovative materials and sustainable industrial solutions in the future [33].

Thus, sulfated compounds derived from phenol–formaldehyde oligomers demonstrate considerable practical potential due to their diverse functional properties and versatile chemical behavior. The sulfation process significantly modifies the physicochemical characteristics of the original oligomer by introducing strongly polar sulfate groups into the molecular structure. As a result of this modification, the materials acquire improved water solubility, enhanced surface activity, and pronounced ionogenic properties, which substantially expand their technological applicability. These functional characteristics enable sulfated phenol–formaldehyde derivatives to act as effective dispersants, emulsifiers, stabilizers, and ion-exchange materials in various industrial systems. Their ability to operate efficiently under demanding chemical conditions makes them particularly valuable in industries such as oil and gas extraction, construction materials production, chemical manufacturing, and environmental protection technologies. Consequently, sulfated phenol–formaldehyde compounds represent a promising direction for further scientific investigation and technological development, especially in the context of designing advanced polymer materials with improved performance and sustainability for future industrial applications.

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Agricultural Sciences

ორგანული მჟავების გამოყენება ფრინველის საკვებში

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ირმა არსენაშვილი

ვეტერინარიის დოქტორი, დარგის ექსპერტი, განათლების ხარისხის
განვითარების ცენტრი

რეზიუმე: ორგანული მჟავები სულ უფრო ხშირად გამოიყენება ფრინველის კვებაში, როგორც ანტიბიოტიკური ზრდის სტიმულატორების ეფექტური ალტერნატივა. ეს კვლევა განიხილავს მათ როლს საკვების უსაფრთხოების, ნაწლავების ჯანმრთელობისა და ზრდის მაჩვენებლების გაუმჯობესებაში. ორგანული მჟავები, როგორიცაა ჭიანჭველმჟავა, პროპიონის და რძემჟავა და ა.შ ავლენენ ძლიერ ანტიმიკრობულ აქტივობას პათოგენების, მათ შორის *Escherichia coli*; *Salmonella spp*; *S. Enteritidis* წინააღმდეგ. მათი საკვებში გამოყენება ხელს უწყობს საკვების შეთვისების უნარიანობის, საკვები ნივთიერებების მონელების გაუმჯობესებას და პროდუქტიულობის ზრდას.

დასკვნები ადასტურებს, რომ ორგანული მჟავების უსაფრთხოდ და ეფექტურად გამოყენება შესაძლებელია, როგორც მდგრადი საკვები დანამატები ფრინველის წარმოებაში. ორგანული მჟავები აუმჯობესებს საჭმლის მომნელებელი სისტემის ჯანმრთელობის მდგომარეობას, ამცირებს ნაწლავებში პათოგენურ მიკროორგანიზმებს და აძლიერებს საზრდო ნივთიერებების მონელებას.

საკვანძო სიტყვები: ორგანული მჟავები; ფრინველის კვება; საკვების უსაფრთხოება; ანტიმიკრობული ეფექტი; სალმონელა; საკვები დანამატები.

USE OF ORGANIC ACIDS IN POULTRY FEED

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Abstract: Organic acids are increasingly used in poultry nutrition as effective alternatives to antibiotic growth promoters. This study reviews their role in improving feed safety, gut health, and growth performance. Organic acids such as formic, propionic, and lactic acids demonstrate strong antimicrobial activity against pathogens including *Salmonella* and *Escherichia coli*. Their inclusion in feed contributes to improved feed conversion ratio, enhanced nutrient digestibility, and increased productivity. The findings confirm that organic acids can be safely and effectively

used as sustainable feed additives in modern poultry production. Organic acids improve gut health, reduce pathogenic microorganisms, and enhance nutrient digestibility.

Keywords: organic acids; poultry nutrition; feed safety; antimicrobial effect; Salmonella; feed additives

მსოფლიო აგრარული საზოგადოება უკანასკნელ პერიოდში ხშირად განიხილავს კომბინირებული საკვების წარმოებისათვის ანტიბიოტიკების შემცველ აუცილებელ ალტერნატივას. 2006 წლის იანვრიდან ანტიბიოტიკების გამოყენება ამ მიზნით აკრძალულია ევროკავშირში. ევროკავშირთან ღრმა და ყოვლისმომცველი თავისუფალი სავაჭრო სივრცის შესახებ (DCFTA) შეთანხმებიდან გამომდინარე. საჭირო გახდა საკანონმდებლო რეგულაციების გადაწყობა საქართველოშიც. ქვეყანამ აიღო ვალდებულება, რომლის საფუძველზეც საკანონმდებლო რეგულაციები უნდა დაუახლოვდეს ევროპულ რეგულაციებს. გამოიცა საქართველოს მთავრობის დადგენილება „ ცხოველის საკვების გამოყენებისა და ბაზარზე განთავსების წესის დამტკიცების შესახებ „ დადგენილება 2024 წელს შევიდა ძალაში, რომლის საფუძველზეც მწარმოებელი ვალდებული გახდა გამოიყენოს მხოლოდ ის ნივთიერებები, რომელიც რეგისტრირებულია ევროკავშირში ცხოველთა კვებაში დასაშვებ ნივთიერებათა ჩამონათვალში. https://ec.europa.eu/food/safety/animal-feed/feed-additives/evaluation-feed-additives-regulation_en იკრძალება ისეთი დანამატების გამოყენება რომელსაც არ აქვს გავლილი ავტორიზაცია. კატალოგები მუდმივად განახლებადია. მწარმოებელმა ამ კუთხით სისტემატიურად უნდა ადევნოს თვალის დაშვების და შესაბამისად ასახოს საკვებწარმოების/საკვებდამზადების ტექნოლოგიის პროცესში.

ამ ფონზე ყველაზე მეტად იკვეთება ორგანული მჟავების როლი და საჭიროება. ფრინველის საკვებში ორგანული მჟავების გამოყენების პოტენციალის გადახედვა მეტად მნიშვნელოვან ამოცანას წარმოადგენს, მაშინ როდესაც მსოფლიოს განვითარებული ქვეყნები უკვე დიდი ხანია ამ პრაქტიკას იყენებს. ჰიგიენური ხარისხის შენარჩუნების მიზნით ცხოველის/ფრინველის კვებაში ორგანული მჟავების ჩართვა ერთ-ერთი მნიშვნელოვანი ღონისძიებაა.

ორგანულ მჟავებს დიდი ყურადღება ექცევა მაღალი კვებითი ღირებულების გამო და არაერთი კვლევით არის დადასტურებული მათი ანტიმიკრობული სარგებელი. როგორც კვლევებით ასევე პრაქტიკული გამოცდილებით დადგენილია ზრდასა და ჯანმრთელობაზე მომქმედის დადებითი ეფექტი, რომელსაც იწვევს ორგანულ მჟავების საფუძველზე წარმოებული დანამატების გამოყენება. ორგანული მჟავების ძირითადი მწარმოებელი ქვეყნებია: შეერთებული შტატები, ჩინეთი, ბრაზილია, მექსიკა და იაპონია.

ყველა მსხვილი კომბინირებული საკვების დანამატების მწარმოებელი კომპანია, უშვებს ექსპლოატაციაში ტექნოლოგიურ ხაზებს, რომელიც ქმნის პროდუქციას ორგანული მჟავების ან მისი მარილების საფუძველზე. მასზე მოთხოვნა იზრდება. ორგანული მჟავები, მაგალითად, პროპიონის მჟავა, 30 წელზე მეტი ხნის განმავლობაში გამოიყენებოდა საკვებში პათოგენური ბაქტერიული მიკროორგანიზმების ზრდის და ობის სოკოების განვითარების შესამცირებლად.

ცხოველის კუჭ-ნაწლავთა სისტემაზე დადებითი მოქმედება ზრდის ეკონომიკურ სარგებელს და ყოველდღიურ მოგებას მეცხოველეობაში. ცხოველების გამოზრდისას შეიძლება მიღწეულ იქნას ორგანული მჟავას დამატებით საკვებად გარდაქმნის უფრო მაღალი მაჩვენებლები.

საკვებში გამოყენებული ორგანული მჟავები და მათი ეფექტი

ორგანული მჟავას დასახელება	ქიმიური ფორმულა	კონცენტრაცია	მიღებული შდეგი/ეფექტიანობა
ფუმარინის მჟავა	COOHCH:CHCOOH	0.5 - 1.0	აუმჯობესებს წონის მატებას და საკვების ეფექტურობას/კონვერსიას როგორც ბროილერში ასევე სადღე გუნდში
პროპიონის მჟავა	$\text{CH}_3\text{CH}_2\text{COOH}$	0.15 – 0.2	იზრდება შენარჩუნების პროცენტული მაჩვენებელი და მცირდება აბდომინალური ცხიმი მამლებში
ვაშლის მჟავა	$\text{COOHCH}_2\text{CH(OH)COOH}$	0.5 – 2.0	იზრდება წონამატი
ასკორბინის მჟავა	$\text{CH}_3\text{CH:CHCH:CHCOOH}$	1.12	იზრდება საკვების ეფექტურობა
ღვინის მჟავა	$\text{COOHCH(OH)CH(OH)COOH}$	0.33	იზრდება წონამატი
რძემჟავა	$\text{CH}_3\text{CH(OH)COOH}$	2.00	უმჯობესდება საკვების ეფექტურობა/ კონვერსია, აომჯობესებს წონის მატებას
ფორმეჟავა	HCOOH	0.5 – 1	ამცირებს PH - ს, და იზრდება ბაქტერიციდული გავლენა Sallmonela - მიმართ
ბენზოიონის მჟავა	$\text{C}_6\text{H}_5\text{COOH}$	0.2	პოზიტიურად მოქმედებს ზრდა-განვითარებაზე
ბუტირის მჟავა	$\text{CH}_3\text{CH}_2\text{COOH}$	0.15	ინარჩუნებს სასარგებლო მიკროფლორას, ხელს უწყობს ნაწლავების უჯრედების გამრავლებას და მდგრადობას

ზემოთ ჩამოთვლილი ორგანული მჟავები, მონოგასტრიტულ ცხოველებში ჩვეულებრივ გამოიყენება როგორც საკვებდანამატი, რომელიც აუმჯობესებს ორგანიზმის საჭმლის მომნელებელი სისტემის მუშაობას, ზრდის საკვების შეთვისების უნარიანობას და საბოლოო პროდუქტიულობას. ორგანული მჟავები ბაზარზე წარმოდგენილია როგორც ნატრიუმის, კალიუმის ან კალციუმის მარილები ასევე თხევადი და ემულსიების სახით.

ტერმინი "ორგანული მჟავა" აღნიშნავს ნაერთების ფართო კლასს, რომელიც გამოიყენება ორგანიზმის ფუნდამენტურ მეტაბოლური პროცესების გასააქტიურებლად. ყველა მჟავას გავლენა არ აქვს ნაწლავის მიკროფლორაზე. ორგანული მჟავები სპეციფიკური ანტიმიკრობული მოქმედებით მოკლე ჯაჭვის მჟავებია (C1 – C7) რომლებიც ბუნებაში ფართოდაა გავრცელებული და ითვლებიან როგორც მცენარეთა ისე ცხოველური ქსოვილების ნორმალურ შემადგენელ ნაწილად. ორგანული მჟავები ასევე წარმოიქმნება ნახშირწყლების მიკრობული დუდილის შედეგად ძირითადად მსხვილ ნაწლავში. ანტიმიკრობული მოქმედების მქონე ორგანულ მჟავების უმეტესობას აქვს PH 3 – დან 5 – მდე. [1]

საკვებში ისეთი მჟავების კომბინაციის გამოყენებისას, როგორიცაა ფორმჟავა, ფუმარინმჟავა, პროპიონმჟავა, რძემჟავა, ასკორბინმჟავა, მცირდება პათოგენის კოლონიზაცია და გამრავლება. სხვადასხვა დროს ჩატარებული სხვადასხვა კვლევები ადასტურებს, რომ სელექციური ორგანული მჟავებით შედგენილი ულუფის/რაციონის გამოყენებისას მაღალია ბროილერის ზრდის მაჩვენებელი, მცირდება დაავადებები და ფრინველის გამოზრდასთან დაკავშირებული პრობლემები.

ორგანულ მჟავებს აქვთ ძლიერი ბაქტერიოსტატიკური ეფექტი და შესაძლებელია გამოყენებული იქნას საკვებში და წყალში, როგორც ფრინველისათვის სალმონელა-მაკონტროლებელი საშუალება.

ბროილერის წარმოების გაუმჯობესებისათვის ერთ-ერთი პირველი მჟავა, რომელიც გამოიყენება, იყო ფორმჟავა. დაკვირვებებმა აჩვენა რომ *Salmonella spp* შემცირდა. [2] შესწავლილია სალმონელასთან ბრძოლის დროს ბროილერში ფორის და პროპიონის მჟავების ნარევის (ორგანული მჟავას ნაზავი იყო 6 კგ /ტ (0.6%)) ეფექტურობა. კვლევებმა დაადასტურა ამ ნარევის გამოყენების დადებითი შედეგი - ნაწლავებში *Salmonella spp*-კოლონიზაციის წინააღმდეგ. [3]

ბროილერის საკვებში კალციუმის ფორმიატის და ბუფერული პროპიონის მჟავას გამოყენებამ მკვეთრად შეამცირა პათოგენური მიკროფლორა ფრინველის ნაწლავში მნიშვნელოვნად შემცირდა ისეთი პათოგენები , როგორიცაა *Escherichia coli* და *Salmonella spp. S. Enteritidis*. [3]

კვლევებით არის დადასტურებული ორგანული მჟავების მარილების კალციუმის დიფორმატის და ნატრიუმის დიფორმატის დადებითი გავლენა 0.3 - 1.2% დოზებით გამოყენებისას. 35 დღის განმავლობაში ხდება პათოგენური მიკროფლორის (სალმონელა, კამპილობაქტერია და ენტერობაქტერია) მნიშვნელოვანი შემცირება და სასარგებლო ბაქტერიების ლაქტობაცილები და ბიფიდობაქტერიების რიცხვის ზრდა. [3] ცდები აჩვენებს, რომ სხვადასხვა ორგანული მჟავები სხვადასხვა ეფექტურობით მოქმედებს ცხოველებსა და ფრინველებზე. დადგენილია, რომ მცირე მოლეკულური მასის საშუალებით გამოყენებული კარბოქსილის მჟავა და ჭინჭველმჟავა აღემატება დანარჩენ ორგანულ მჟავებს ბაქტერიოსტატიკური და ბაქტერიოციდული თვისებებით. სუფთა ჭინჭველმჟავა ისევე როგორც სხვა მჟავები სამიშია კანზე ან თვალში მოხვედრის დროს, აქვს მძაფრი სურნელი, რაც ართულებს მასთან მუშაობას. ორმაგი მჟავე მარილები ნატრიუმის დიფორმიატები უფრო მეტად უსაფრთხოა გამოყენებისათვის მას არ აქვს მძაფრი სურნელი, წარმოდგენილი არის ფხვნილის სახით და შენარჩუნებული აქვს ანტიბაქტერიული თვისებები.

მეცნიერებმა შეისწავლეს აგრეთვე საკვები ნივთიერებების ბალანსი ბროილერისათვის ნატრიუმის ფორმიატის სხვადასხვა დოზით გამოყენების შემთხვევაში (3/6/12 კილოგრამი ერთ ტონა კომბინირებულ საკვებზე). გამოკვლევებმა აჩვენა, რომ საკვების ენერგეტიკული ღირებულება სამივე შემთხვევაში გაიზარდა. დიფორმიატის დოზირების ზრდის პარალელურად მოიმატა ცოცხალი მასის წონამ.

დიფორმიატები აძლიერებს საკვები ნივთიერებების გადამუშავებას ბროილერის საკვებში. მეცნიერებმა კვლევებით დაადგინეს, რომ კალციუმის დიფორმიატის

გამოყენებისას (დოზირება 18 კგ. 1 ტონა კომბინირებულ საკვებზე) გაიზარდა მთლიანი ენერგია 1,92 %-ით, პროტეინი 2,35 %-ით, ფოსფორი 8,1 %-ით და კალციუმი 3,7 %-ით.[4] ნატრიუმის დიფორმიატი კალიუმის დიფორმიატისაგან განსხვავდება ჭიანჭველმჟავის შემცველობის დონით (80 % ნატრიუმის დიფორმიატი; 70% კალიუმის დიფორმიატი), ასევე ნატრიუმის დიფორმიატი უფრო იაფია, ვიდრე კალიუმის. ბროილერის თანამედროვე კროსების გამოზრდის პროცესში ეფექტურად გამოიყენება მხოლოდ ნატრიუმის დიფორმიატი, რადგან საკვები ისედაც მდიდარია კალიუმით, სოიოს შროტის აქტიური მოხმარების გამო.

ნატრიუმის დიფორმიატი ასევე განაპირობებს დისბაქტერიოზით დაავადების რისკის შემცირებას. აზოტის მაღალი შეკავება გვაძლევს უკანა კუჭ-ნაწლავში ამიაკის შემცველობის შემცირებას. მიკროფლორა არის ნაკლებად ტუტე, ამიტომ ნაკლებად ხელსაყრელი პირობები იქმნება დაავადებების დამომწვევი ბაქტერიების გასამრავლებლად და ხელსაყრელი პირობები იქმნება იმ ბაქტერიებისათვის, რომლებიც გამოიმუშავებენ რძემჟავას. აქედან გამომდინარე არ არის აუცილებელი იმაზე საუბარი, რომ ეს გვაძლევს ზრდის მასტიმულირებელ ეფექტს ცხოველებსა და ფრინველებში.

საქართველოში ჩატარდა კვლევა რომლის მიზანი იყო ორგანული მჟავების, როგორც ანტიბიოტიკების შემცველების ეფექტის შეფასება. გაიზომა საკვების მოხმარების, სხეულის წონის მომატებისა და საკვების კონვერსიის მაჩვენებლები ბროილერის წიწილებში სხვადასხვა ზრდის ფაზაში.

ანტიბიოტიკები და ორგანული მჟავები ჩართული იყო საკვებში სხვადასხვა კომბინაციით. ცდაში მონაწილეობდა 400 ფრინველი, გამოზრდის პერიოდი 45 დღე.

შედეგები: ფრინველების ზრდის მაჩვენებლები, სხეულის წონის მატების და საკვების კონვერსიის თვალსაზრისით მნიშვნელოვნად გაუმჯობესდა.

შეგვიძლია შევაჯამოთ ორგანული მჟავების გამოყენების ეფექტურობა:

- ორგანული მჟავები (ჭიანჭველმჟავა, კარბოქსილმჟავა, ძმარმჟავა, რძემჟავა და სხვა) ცვლიან ორგანიზმის PH-ს, რის გამოც ორგანიზმი უფრო კარგად უმკლავდება სხვადასხვა ინფექციებს.
- ზრდის საკვების ენერგეტიკულ ღირებულებას (ნატრიუმის დიფორმიატის რაციონში ჩართვა ზრდის ენერგიას 0,67 %-ით (22,7 კკალორია 1 კილოგრამ საკვებზე).
- იწვევს აზოტის შეკავებას, კუჭ-ნაწლავთა სისტემის მიერ მის გაძლიერებული შეწოვის გავლენით იზრდება ამინომჟავების შეთვისებისუნარიანობა. აზოტის შეკავების გაუმჯობესების საშუალო მაჩვენებელი კალიუმის დიფორმიატის გამოყენებისას შეადგენს 0,364 %.
- ზრდის საკვების შეთვისებისუნარიანობას. მაგალითად, კომბინირებული საკვები შეიცავს ლიზინს 1,2 %, 1 ტონა შეიცავს 12 კილოგრამს. თუკი 1 კილოგრამი კალიუმის დიფორმიატი აუმჯობესებს გადამუშავებას 0.364% (12×0.364) დამატებით ვღებულობთ 0.044 კგ ლიზინს 1 ტონა საკვებზე. ნატრიუმის დიფორმიატის შემთხვევაში ეს მაჩვენებელი შეადგენს 0,05კგ-ს.
- ცდებმა და პრაქტიკამ დაადასტურა, რომ დიფორმიატების საფუძველზე დამზადებული საკვები დანამატები უზრუნველყოფენ დამატებითი ენერგიის გამოიმუშავებას და ზრდის საზრდო ნივთიერებების შეთვისების უნარს.

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Legal Sciences

Strengthening Anti–Money Laundering Safeguards in U.S. Immigration Programs: Regulatory Gaps and Policy Solutions for Protecting Financial Integrity

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Abstract

The globalization of migration has increasingly intersected with international financial flows. Immigration systems, particularly those involving investment migration, employment sponsorship, and cross-border financial transfers serve as legitimate channels for economic mobility, labor market development, and international cooperation. At the same time, these systems may inadvertently create opportunities for illicit financial activity. Money laundering remains one of the most persistent threats to financial integrity worldwide, as criminal actors attempt to disguise the origin of unlawful proceeds by integrating them into legitimate economic systems.

The United States maintains one of the most sophisticated anti–money laundering (AML) frameworks globally, primarily through statutory mechanisms such as the Bank Secrecy Act and related financial reporting requirements administered by the Financial Crimes Enforcement Network. Despite these regulatory mechanisms, immigration programs are not always fully integrated into the broader financial compliance framework. Certain immigration pathways involve significant financial transfers and business investments, which may create potential vulnerabilities if oversight mechanisms are insufficient.

This article examines the intersection between U.S. immigration programs and anti–money laundering enforcement. It identifies structural regulatory gaps, including challenges in verifying foreign sources of wealth, limited financial monitoring obligations for certain professional intermediaries, and institutional coordination barriers among government agencies. The article further proposes policy reforms designed to strengthen financial transparency while preserving the economic and humanitarian benefits of immigration. Enhanced interagency collaboration, improved due diligence mechanisms, and the integration of financial intelligence tools into immigration oversight could significantly strengthen the integrity of the U.S. immigration system.

I. Introduction

Money laundering is widely recognized as a major threat to global financial stability, economic governance, and national security. Criminal organizations routinely employ complex financial strategies to disguise the origins of illicit proceeds, allowing those funds to enter legitimate financial systems. Governments worldwide have responded by establishing comprehensive regulatory frameworks designed to detect suspicious transactions and prevent illicit financial integration.¹

Despite the expansion of anti–money laundering regulation, globalization has significantly increased the complexity of financial oversight. Criminal actors often move funds across multiple

jurisdictions to exploit regulatory gaps, differences in legal frameworks, and variations in enforcement capacity.²

Within this global financial landscape, immigration systems may unintentionally intersect with laundering activities. Immigration programs frequently involve significant cross-border financial transfers, investment capital, or business ownership structures. Although these financial activities are typically lawful and economically beneficial, they may also present opportunities for individuals seeking to integrate illicit wealth into legitimate economic systems.

The United States operates one of the most complex immigration frameworks in the world. Programs administered by agencies such as the U.S. Citizenship and Immigration Services and the Department of Homeland Security include family-based immigration, employment-based visas, humanitarian protections, and investment-related pathways. These programs serve essential economic and social functions by promoting labor mobility, encouraging international investment, and supporting family reunification.

However, several immigration pathways involve large financial transactions that may present regulatory challenges. Investment-based immigration programs, for example, require applicants to demonstrate that substantial financial resources originate from lawful sources. Verifying such claims can be difficult when documentation originates from foreign jurisdictions with varying levels of financial transparency.

This article argues that the intersection between immigration policy and financial crime prevention deserves greater scholarly and regulatory attention. While immigration systems are not inherently vulnerable to money laundering, certain structural characteristics may create opportunities for illicit financial activity if oversight mechanisms are insufficient.

The article proceeds in four parts. Part II examines the structure of money laundering and its relationship to transnational financial systems. Part III analyzes financial vulnerabilities within selected U.S. immigration programs. Part IV discusses regulatory gaps and institutional challenges that complicate effective oversight. Finally, Part V proposes policy reforms designed to strengthen financial transparency while maintaining the accessibility and legitimacy of the U.S. immigration system.

II. The Structure of Money Laundering in Transnational Financial Systems

Money laundering generally occurs through a three-stage process consisting of placement, layering, and integration.³

The placement stage involves introducing illicit funds into the financial system. Criminal actors may accomplish this by depositing cash into financial institutions, purchasing financial instruments, or making investments through business entities.

The layering stage consists of a series of complex financial transactions designed to obscure the origin of the funds. These transactions often involve international transfers, shell companies, and offshore financial accounts.

Finally, the stage of integration occurs when laundered funds reenter the legitimate economy in the form of lawful assets, such as business investments, real estate purchases, or corporate holdings.

Transnational economic activity plays an important role in facilitating these processes. Criminal actors frequently exploit differences between national regulatory systems by transferring funds through multiple jurisdictions. International investment structures, corporate entities, and property acquisitions can therefore function as mechanisms for integrating illicit wealth into legitimate financial markets.

Immigration-related investments may intersect with the integration stage of this laundering process. For example, individuals seeking immigration benefits through investment programs may transfer significant capital into business ventures or development projects. Although these

investments are typically legitimate, they may theoretically provide opportunities for the integration of illicit financial resources.

III. Financial Vulnerabilities in Selected U.S. Immigration Programs

Certain immigration programs involve financial structures that could potentially intersect with money laundering risks. Investment-based immigration pathways provide one of the most frequently discussed examples.

Programs such as the EB-5 Immigrant Investor Program allow foreign nationals to obtain lawful permanent residence by making substantial investments in U.S. enterprises that generate employment opportunities. Congress established the program through the Immigration Act of 1990 to encourage foreign investment and economic development.

Applicants must demonstrate that their investment capital originates from lawful sources. However, verifying foreign financial documentation can be challenging for several reasons. Financial records may originate from jurisdictions with limited transparency, corporate ownership structures may be complex, and beneficial ownership may be obscured through multiple layers of legal entities.

Employment-based immigration programs may also present potential vulnerabilities. In certain circumstances, criminal actors could attempt to establish shell companies designed to sponsor immigration petitions while simultaneously facilitating financial misconduct. Although regulatory safeguards exist to prevent such abuse, enforcement challenges may arise when financial activity occurs across multiple jurisdictions.

Family-based immigration pathways may also involve cross-border financial transfers intended to support relatives relocating to the United States. While these transfers are generally legitimate, they may occasionally involve informal financial networks or undocumented sources of wealth that complicate oversight efforts.

IV. Regulatory Gaps and Institutional Coordination Challenges

One of the most significant challenges in addressing money laundering risks within immigration systems is the fragmentation of regulatory oversight.

Financial institutions are subject to extensive AML compliance obligations under the Bank Secrecy Act, including customer identification requirements and suspicious activity reporting obligations. These requirements are enforced by the Financial Crimes Enforcement Network.

However, immigration-related financial transactions may also involve professional intermediaries such as attorneys, business consultants, and financial advisors. These professionals play important roles in facilitating lawful immigration applications but may not always fall within the same AML reporting framework as regulated financial institutions.

Another challenge involves coordination between government agencies responsible for immigration policy and those responsible for financial regulation. Immigration agencies primarily focus on eligibility requirements and legal compliance, while financial regulators concentrate on detecting financial crimes.

Without strong information-sharing mechanisms, suspicious financial patterns associated with immigration transactions may go undetected.

International cooperation presents an additional challenge. Investigating the origin of foreign wealth frequently requires access to banking records, tax documentation, and corporate registries located in other jurisdictions. Differences in legal frameworks and data privacy rules may complicate these investigations.

V. Policy Recommendations

Strengthening financial integrity within immigration programs requires a balanced regulatory approach that protects national security while preserving the benefits of lawful immigration.

First, regulators should enhance source-of-funds verification procedures for immigration programs involving substantial financial investments. Independent financial audits and improved documentation requirements could significantly improve oversight.

Second, policymakers should encourage greater interagency collaboration between immigration authorities and financial regulators. Joint investigative task forces and integrated data-sharing systems could help detect suspicious financial patterns associated with immigration-related transactions.

Third, policymakers should consider expanding financial transparency expectations for certain professional intermediaries involved in high-value immigration investments while maintaining appropriate confidentiality protections.

Fourth, emerging technologies—including artificial intelligence and financial data analytics—could improve regulatory capacity by identifying unusual transaction patterns associated with potential laundering schemes.

Finally, strengthening international financial cooperation agreements would improve regulators' ability to verify foreign sources of wealth and investigate cross-border financial activity.

Illustrative Example

Consider a hypothetical investor seeking lawful permanent residence through an investment-based immigration program. The investor transfers several million dollars through multiple offshore corporations registered in different jurisdictions. Each transaction individually appears legitimate, but the layered corporate structure obscures the origin of the funds.

Without robust source-of-funds verification procedures and effective interagency coordination, regulators may struggle to determine whether the investment capital originates from legitimate business activity or illicit financial conduct. Enhanced financial due diligence and improved access to international financial records could significantly reduce such risks.

VI. Author's Perspective

In the author's view, the intersection between immigration policy and financial regulation remains an underexplored area of legal scholarship. Immigration programs are often evaluated primarily through humanitarian or economic frameworks, while their relationship to financial crime prevention receives comparatively limited attention.

Integrating immigration oversight with broader anti-money laundering frameworks would strengthen both policy domains. Such reforms would deter illicit financial activity while reinforcing public confidence in the transparency and integrity of immigration programs.

VII. Conclusion

U.S. immigration programs play a crucial role in promoting economic development, innovation, and international cooperation. However, the financial transactions associated with these programs may also create opportunities for illicit actors to exploit regulatory gaps.

Addressing these vulnerabilities does not require restricting lawful immigration pathways. Instead, policymakers should focus on strengthening the integration between immigration oversight and financial crime prevention frameworks.

Improved source-of-funds verification enhanced interagency coordination, and greater financial transparency can significantly reduce money laundering risks while preserving the benefits of lawful immigration.

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UNMASKING BENEFICIAL OWNERS: CORPORATE TRANSPARENCY LAWS FOR REAL ESTATE MARKETS AND NATIONAL SECURITY

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INTRODUCTION

In the United States, Limited Liability Companies (LLCs) are widely used as vehicles for property ownership, from small-scale rental/purchase investments to large institutional ones. While LLCs provide important benefits, including limited liability protection and operational flexibility, their ability to shield Beneficial Owners (BOs) from public view has long been a source of concern for regulators, law enforcement, and communities. Anonymity of BO for LLCs in real estate transactions has been linked to financial crime, including money laundering, tax evasion, and foreign influence, while also complicating housing regulation in jurisdictions experiencing sharp increases in corporate real estate ownership.¹

Ongoing legislative developments represent a shift toward transparency at the federal level with the implementation of Corporate Transparency Act (CTA)² which requires companies to disclose BO information (BOI) to the Department of the Treasury's Financial Crimes Enforcement Network (FinCEN).³ Recently however, interim final rule was issued by FinCEN effective March 2025 due to ongoing litigation *Texas Top Cop Shop, Inc. v. Garland*⁴ exempting US based corporations' requirement to file BOI temporarily.⁵ At the state level, New York is set to enact its own LLC Transparency Act built on CTA but with a stronger public access component.⁶ In contrast, implementation of such effective transparency regime in the state of Delaware is lacking, especially considering that Delaware is known to be the leading LLC incorporation state in the US.

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¹ FinCEN, *Advisory to Financial Institutions and Real Estate Firms on Illicit Finance Risks in the Real Estate Sector*, FIN-2023-A001 (2023), <https://www.fincen.gov/boi>;

² Corporate Transparency Act, 31 U.S.C. § 5336 (2021) <https://www.congress.gov/116/plaws/publ283/PLAW-116publ283.pdf>.

³ *Id.*

⁴ *Texas Top Cop Shop, Inc. v. Garland*, No. 5:23-cv-00045 (N.D. Tex. 2025).

⁵ FinCEN, *Beneficial Ownership Information Reporting*, <https://www.fincen.gov/boi>; see Arpita Shroff & Diana Pence, *The Mandate of the Corporate Transparency Act*, 142 J. Tax'n 18 (Jan./Feb. 2025), <https://1.next.westlaw.com/Document/I3415e363660311f090a092159c9c2a82/View/FullText.html>

⁶ See Sidley Austin LLP, *Key Things to Know About the New York LLC Transparency Act* (2024); see N.Y. S. 995, amendment B (2023) (limited liability company beneficial owner disclosure); N.Y. Assemb. A.08544 (2023) (same), <https://www.nysenate.gov/legislation/bills/2023/S995/amendment/B>, <https://nyassembly.gov/leg/?term=2023&bn=S00995>, https://nyassembly.gov/leg/?default_fld=&leg_video=&bn=A08544&term=2023&Summary=Y&Actions=Y&Memo=Y&Text=Y (signed in 2023, effective Jan. 2026).

⁷ *Incorporate in Delaware or Nevada*, Wolters Kluwer, <https://www.wolterskluwer.com/en/expert-insights/why-incorporate-in-delaware-or-nevada>.

Therefore, it is imperative to understand that effective corporate transparency laws demonstrate a growing recognition that disclosure requirements are not only about mitigating illicit financing and thereby protecting national interest, but also about strengthening trust in real estate markets by enabling more effective regulation of institutional landlords.

This paper outlines that the effectiveness of corporate transparency in the United States depends on consistent and enforceable disclosure of beneficial ownership information across federal and state levels. Through comparative analysis of the Corporate Transparency Act and Delaware's Limited Liability Company Act (DLLCA), it argues that gaps in beneficial ownership transparency not only enable the misuse of real estate investments for illicit financial activity but also undermine market integrity, housing stability, and national security.

This Research Paper proceeds as follows: Chapter I outlines the growing concerns surrounding corporate anonymity and minimal disclosure requirements in real estate transactions involving limited liability companies, explaining how the concealment of beneficial ownership facilitates illicit financial activity, distorts housing markets, and implicates national security interests. Chapter II analyzes the applicable legal frameworks by comparing the federal Corporate Transparency Act with Delaware's Limited Liability Company Act, while briefly referencing New York's LLC Transparency Act to illustrate emerging state-level efforts to align with federal transparency objectives. Chapter III examines the constitutional implications arising from the divergence between federal transparency mandates and state incorporation practices, focusing on how this misalignment disrupts the federal–state balance of powers, frustrates transparency objectives in real estate markets, and weakens the effectiveness of national financial crime enforcement. Chapter IV concludes with my proposed reforms, grounded in the preceding analysis, addressing the Corporate Transparency Act, recent FinCEN developments, and Delaware state law, and emphasizing the critical role of effective transparency measures in preserving real estate market integrity, strengthening national security, ensuring regulatory compliance, and mitigating the misuse of corporate formation autonomy for financial misconduct. Finally, the Research Paper concludes by summarising these findings to underscore the necessity of coordinated transparency reforms across federal and state regimes on an urgent basis.

I. GROWING CONCERNS SURROUNDING CORPORATE ANONYMITY IN REAL ESTATE MARKETS AND NATIONAL SECURITY

In recent years, the United States has witnessed a noticeable rise in the use of LLCs and similarly opaque corporate structures to acquire real estate; from single-family homes and multifamily rentals to large-scale commercial portfolios.⁸ While LLCs offer legitimate benefits such as limited liability, tax efficiency, and operational flexibility, capacity to conceal beneficial ownership, these very advantages have fostered an environment where anonymity could be exploited.⁹ Exploitation is primarily done by allowing bad actors to channel illicit funds through real estate transactions by money laundering, evading tax, and circumventing sanctions thereby posing serious regulatory, market, and national security concerns.¹⁰ When property is purchased through entities whose true owners remain undisclosed, these entities become safe havens for illicit capital, undermining

⁸ See Jon Lin, *LLCs, Luxury Real Estate, and Secrecy*, N.Y.U. J. Legis. & Pub. Pol'y: Quorum (2023), <https://nyuillpp.org/quorum/jonlin-llcs-luxury-real-estate-secrecy/>.

⁹ See U.S. Dep't of the Treasury, *National Money Laundering Risk Assessment* (2024), <https://home.treasury.gov/system/files/136/2024-National-Money-Laundering-Risk-Assessment.pdf>; Int'l Consortium of Investigative Journalists, *U.S. Takes Aim at Real Estate Money Laundering*, Pandora Papers (2024), <https://www.icij.org/investigations/pandora-papers/us-takes-aim-at-real-estate-money-laundering/?utm>.

¹⁰ *Id.*

governmental oversight and depriving communities of transparency and disabling accountability of BOs.¹¹ Additionally, this lack of transparency affects housing protection and affordability, as concealed ownership allows unpredictable investments causing inflation in property values which causes most detriment to potential residential real estate owners, thereby displacing communities.¹² The concept of safeguarding real estate markets in this context refers to ensuring that both commercial and residential property markets remain transparent, affordable, and free from manipulation by illicit capital.¹³

A beneficial owner under the CTA is “any individual who, directly or indirectly, either exercises substantial control over a reporting company or owns or controls at least 25% of the ownership interest of a reporting company.”¹⁴ Disclosure of BO information during LLC formation means the requirement to reveal relevant information of the BO to the government authorities.¹⁵ FinCEN has repeatedly emphasized on the same reminding that the opacity of real estate transactions enables foreign oligarchs, sanctioned individuals, and criminal organizations to launder funds through the US market.¹⁶ BO transparency empowers regulators and communities to identify the true stakeholders in property markets, enabling effective enforcement of zoning, tax, and housing policies based on accurate ownership data.¹⁷ Conversely, LLC anonymity frustrates these objectives by impeding governments’ ability to monitor absentee ownership and preserve community stability.¹⁸

CTA represents the most significant federal step toward correcting these deficiencies. It is enacted under the National Defense Authorization Act for Fiscal Year 2021 whereby it requires most LLCs to report their BO information to FinCEN.¹⁹ Although this marks a significant federal step toward curbing corporate anonymity, varying state-level disclosure requirements, particularly in

¹¹ U.S. Dep’t of the treasury, national Money laundering Risk Assessment (2022), <https://home.treasury.gov/system/files/136/2022-National-Money-Laundering-Risk-Assessment.pdf>.

¹² See *Money Laundering Risks in Commercial Real Estate*, ACDC & Global Financial Integrity (May 2024), https://acdatacollective.org/wp-content/uploads/2024/05/Money-Laundering-Risks-in-Commercial-Real-Estate_ACDC_GFI_FACT.pdf?utm

¹³ See U.S. Dep’t of the Treasury, *National Illicit Finance Strategy 2024*, at 32 (defining safeguarding of property markets as a national security priority), <https://home.treasury.gov/system/files/136/2024-Illicit-Finance-Strategy.pdf>

¹⁴ Corporate Transparency Act, 31 U.S.C. § 5336 (2021). <https://www.congress.gov/116/plaws/publ283/PLAW-116publ283.pdf>

¹⁵ *Id.*

¹⁶ See **FinCEN**, *Advisory to Financial Institutions and Real Estate Firms on Illicit Finance Risks in the Real Estate Sector*, FIN-2023-A001 (2023), https://www.fincen.gov/system/files/shared/sar_tti_23.pdf

¹⁷ See U.S. Dep’t of the Treasury, *National Illicit Finance Strategy 2024*, at 32 (defining safeguarding of property markets as a national security priority), <https://home.treasury.gov/system/files/136/2024-Illicit-Finance-Strategy.pdf>; *Money Laundering Risks in Commercial Real Estate*, ACDC & Global Financial Integrity (May 2024), https://acdatacollective.org/wp-content/uploads/2024/05/Money-Laundering-Risks-in-Commercial-Real-Estate_ACDC_GFI_FACT.pdf?utm.

¹⁸ See Qian Franklin, *Paper Pre-WFA 2024*, Haas School of Business (2024), <https://haas.berkeley.edu/wp-content/uploads/Qian-Franklin-Paper-Pre-WFA-2024.pdf>, See **FinCEN**, *Advisory to Financial Institutions and Real Estate Firms on Illicit Finance Risks in the Real Estate Sector*, FIN-2023-A001 (2023), https://www.fincen.gov/system/files/shared/sar_tti_23.pdf

¹⁹ Corporate Transparency Act, 31 U.S.C. § 5336 (2021). <https://www.congress.gov/116/plaws/publ283/PLAW-116publ283.pdf>

incorporation-friendly jurisdiction such as Delaware, continue to create transparency gaps²⁰ which will be examined with greater depth in Chapter II and III.

II. COMPARATIVE LEGAL FRAMEWORKS (CTA AND THE DLLCA)

The comparative framework between federal and state legislation reveals the structural imbalance between the CTA²¹ and the DLLCA²² in terms of beneficial ownership disclosure. The CTA in association Anti-Money Laundering Act of 2020,²³ establishes a federal mandate requiring reporting corporations to disclose their beneficial owners and company applicants to the FinCEN.²⁴ This federal standard represents a breakpoint effort in the United States to combat the misuse of corporate structures, especially LLCs used for financial crime especially money laundering, tax evasion, and concealment of illicit wealth through real estate space.²⁵

Under CTA 31 U.S.C. § 5336(b)(1)(A)²⁶, entities formed or registered to do business in the United States must report identifying information for their beneficial owners, including name, date of birth, address, and a unique identification number from an acceptable document such as a passport or driver's license.³ This disclosure requirement aims to provide FinCEN with a centralized database of ownership information accessible to law enforcement and certain regulatory authorities.²⁷

In contrast, Delaware's LLC Act long considered a hallmark state for upholding corporate flexibility requiring only minimal information at formation whereby as per requirement, the certificate of incorporation merely needs to include the LLC's name, the address of its registered office, and the name of its registered agent.²⁸ Delaware imposes no statutory obligation to identify or report beneficial owners publicly or even privately to state regulators.²⁹ While this approach preserves business privacy and administrative ease, it also fosters opacity, allowing anonymous BOs and shell entities to operate within and beyond state boundaries.⁷

²⁰ See Del. Code Ann. tit. 6, ch. 18, subch. II, https://delcode.delaware.gov/title6/c018/sc02/index.html?utm_source.

²¹ Corporate Transparency Act, 31 U.S.C. § 5336 (2021), <https://www.congress.gov/116/plaws/publ283/PLAW-116publ283.pdf>

²² See Del. Code Ann. tit. 6, ch. 18, subch. II, https://delcode.delaware.gov/title6/c018/sc02/index.html?utm_source.

²³ Anti-Money Laundering Act of 2020, Pub. L. No. 116-283, div. F, § 6001-6511, 134 Stat. 4547 (2021) <https://www.congress.gov/116/plaws/publ283/PLAW-116publ283.pdf>

²⁴ Corporate Transparency Act, 31 U.S.C. § 5336 (2021). <https://www.congress.gov/116/plaws/publ283/PLAW-116publ283.pdf>

²⁵ See The Mandate of the Corporate Transparency Act, 98 Notre Dame L. Rev. 451, 456–58 (2025) <https://scholarship.law.nd.edu/cgi/viewcontent.cgi?article=1726&context=jleg>

²⁶ *Id.*

²⁷ See FinCEN, *Beneficial Ownership Information Reporting Requirements* (Final Rule) <https://www.fincen.gov/boi>, <https://www.fincen.gov/news/news-releases/fincen-removes-beneficial-ownership-reporting-requirements-us-companies-and-us?utm>

²⁸ See *Why Incorporate in Delaware or Nevada*, Wolters Kluwer (2024), <https://www.wolterskluwer.com/en/expert-insights/why-incorporate-in-delaware-or-nevada>; Del. Code Ann. tit. 6, § 18-201(a) (2024).

²⁹ *Id.*; see Delaware Div. of Corps., *LLC Filing and Formation Requirements* (2024), [https://1.next.westlaw.com/Browse/Home/StatutesCourtRules/DelawareStatutesCourtRules?guid=N8EF1D440B7AD11DB8E46AD894CF6FAAB&originationContext=documenttoc&transitionType=Default&contextData=\(sc.Default\)\)](https://1.next.westlaw.com/Browse/Home/StatutesCourtRules/DelawareStatutesCourtRules?guid=N8EF1D440B7AD11DB8E46AD894CF6FAAB&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default))).

This divergence between the CTA's federal transparency mandate and Delaware's state-level opacity demonstrates a continuing gap between national policy goals and state business practices. The result is a divided regulatory landscape in which beneficial ownership transparency depends not on uniform compliance across nation, but on the jurisdiction of incorporation.³⁰

The gap has recently been intensified by FinCEN's March 2025 interim final rule, which temporarily suspended beneficial ownership reporting obligations for US corporations³¹ following ongoing litigation in *Texas Top Cop Shop, Inc. v. Garland*.³² This development has reignited debate over the limits of federal authority and the extent to which state autonomy can frustrate nationwide transparency objectives. The temporary exemption also encourages arguments from incorporation-friendly jurisdictions that oppose federal disclosure mandates upon states' rights to regulate entity formation³³ which potentially exposes CTA to risk of losing its credibility nationwide.

Meanwhile, New York has newly enacted amendments to its LLC law effective January 1, 2026, that reporting LLCs disclose their beneficial owners to the State Department of State in a manner consistent with CTA obligations³⁴ thereby harmonizing state-level transparency with federal principles.³⁵ Although the Act's implementation is yet to take effect, it demonstrates how a state such as New York with substantial real estate markets are progressively adopting federal transparency ideals.³⁶

The purpose of comparative analysis of legal frameworks discussed thus far through this paper uncovers a pivotal truth; that the effectiveness of beneficial ownership transparency in the United States cannot depend solely on federal reforms, but also on the establishment of greater uniformity and consistency across state jurisdictions, ensuring that regulatory objectives are met comprehensively and that gaps exploited for illicit purposes are effectively mitigated (both proactively and reactively as required). Federal initiatives such as the CTA cannot fully deter illicit financial flows in the real estate sector on its own unless states with immensely high incorporation volumes like Delaware adopt consistent disclosure standards. Until such alignment is achieved, the interplay between federal ambition and state discretion will continue to define the limits, or

³⁰ See Arpita Shroff & Diana Pence, *The Mandate of the Corporate Transparency Act*, 142 J. Tax'n 18 (Jan./Feb. 2025),

<https://1.next.westlaw.com/Document/I3415e363660311f090a092159c9c2a82/View/FullText.html>

³¹ <https://www.fincen.gov/boj>, See Arpita Shroff & Diana Pence, *The Mandate of the Corporate Transparency Act*, 142 J. Tax'n 18 (Jan./Feb. 2025),

<https://1.next.westlaw.com/Document/I3415e363660311f090a092159c9c2a82/View/FullText.html>

³² See FinCEN, *Interim Final Rule on Beneficial Ownership Reporting Requirements* (Mar. 2025), See Arpita Shroff & Diana Pence, *The Mandate of the Corporate Transparency Act*, 142 J. Tax'n 18 (Jan./Feb. 2025),

<https://1.next.westlaw.com/Document/I3415e363660311f090a092159c9c2a82/View/FullText.html>, See *Texas Top Cop Shop, Inc. v. Garland*, No. 5:23-cv-00045 (N.D. Tex. 2025), <https://www.fincen.gov/news/news-releases/fincen-removes-beneficial-ownership-reporting-requirements-us-companies-and-us?utm>

³³ See *Texas Top Cop Shop, Inc. v. Garland*, No. 5:23-cv-00045 (N.D. Tex. 2025).

³⁴ See N.Y. Sen. Bill S.995 (2023), Amendment B (limited liability company beneficial owner disclosure) (as proposed); N.Y. Assembly Bill A.08544 (2023) (same); see also Sidley, *Key Things to Know About the New York LLC Transparency Act* (Mar. 2024) <https://www.sidley.com/en/insights/newsupdates/2024/03/key-things-to-know-about-the-new-york-llc-transparency-act>

³⁵ *Id.*

³⁶ *Id.*

lack thereof in relation to transparency in American legal landscapes³⁷, which shall be discussed in detail in the following Chapter.

III. CONSTITUTIONAL IMPLICATIONS

The CTA was enacted pursuant to Congress's authority under the Commerce Clause and its national security powers, reflecting explicit congressional findings that anonymous shell companies pose a serious threat to the integrity of the US financial system and facilitate money laundering, terrorism financing, sanctions evasion, and foreign corruption.³⁸ By requiring reporting companies to disclose beneficial ownership information directly to the FinCEN, Congress sought to establish a uniform federal mechanism (through enactment of CTA) capable of addressing risks that transcend state boundaries.³⁹ However, the CTA does not preempt state corporate formation statutes, nor does it compel states to modify their incorporation practices.⁴⁰

Delaware's LLC Act exemplifies the constitutional tension created by this dual system; as the leading jurisdiction for LLC formation in the United States, Delaware requires only minimal information at the time of formation, collecting no beneficial ownership data and imposing no verification obligations on organizers or registered agents.⁴¹ While this approach is often justified as promoting business efficiency and flexibility, it creates a structural gap between federal transparency objectives and state-level practices.⁴² In effect, Delaware's refusal to adopt even baseline disclosure measures undermines the cooperative functioning of the federal regime by allowing entities formed under its laws to remain opaque at the point of entry into the US economy.⁴³

Therefore, this misalignment disrupts the constitutional equilibrium between federal and state authority. When anonymous LLCs formed under Delaware law are used to acquire real estate across state lines, launder illicit funds, or evade federal sanctions, the consequences are borne not only by Delaware but by the national economy and federal enforcement agencies.⁴⁴

The constitutional strain has been further amplified by recent developments in federal enforcement. In March 2025, FinCEN issued an interim final rule temporarily exempting US based entities from beneficial ownership reporting requirements following ongoing litigation in *Texas Top Cop Shop, Inc. v. Garland*.⁴⁵ This development further reveals the fragility of the federal

³⁷ See Corporate Transparency Act § 5336(h); see also Del. Code Ann. tit. 6, § 18-201

³⁸ Anti-Money Laundering Act of 2020, Pub. L. No. 116-283, div. F, §§ 6001–6511, 134 Stat. 4547 (2021), <https://www.congress.gov/116/plaws/publ283/PLAW-116publ283.pdf>

³⁹ 31 U.S.C. § 5336(b), <https://www.law.cornell.edu/uscode/text/31/5336?utm>

⁴⁰ *Id.*

⁴¹ Del. Code Ann. tit. 6, § 18-201, <https://delcode.delaware.gov/title6/c018/sc02/index.html>

⁴² *Id.*, See Arpita Shroff & Diana Pence, *The Mandate of the Corporate Transparency Act*, 142 J. Tax'n 18 (Jan./Feb. 2025),

<https://1.next.westlaw.com/Document/I3415e363660311f090a092159c9c2a82/View/FullText.html>

⁴³ *Id.*

⁴⁴ See Arpita Shroff & Diana Pence, *The Mandate of the Corporate Transparency Act*, 142 J. Tax'n 18 (Jan./Feb. 2025),

<https://1.next.westlaw.com/Document/I3415e363660311f090a092159c9c2a82/View/FullText.html>

⁴⁵ FinCEN, Beneficial Ownership Information Reporting, <https://www.fincen.gov/boi>, *Texas Top Cop Shop, Inc. v. Garland*, No. 5:23-cv-00045 (N.D. Tex. 2025), <https://www.fincen.gov/news/news-releases/fincen-removes-beneficial-ownership-reporting-requirements-us-companies-and-us?utm>

transparency framework when state-level incorporation regimes remain opaque.⁴⁶ In the absence of meaningful state cooperation, the temporary suspension of federal reporting obligations risks re-entrenching the very anonymity the CTA was designed to dismantle.⁴⁷

The implications of this constitutional imbalance are particularly acute in the real estate sector. Real estate transactions have long been identified by FinCEN and other authorities as a preferred channel for laundering illicit funds due to high asset values, limited disclosure requirements, and historically weak AML oversight.⁴⁸ Where state incorporation laws permit anonymous entities to operate freely, federal efforts to monitor and regulate real estate markets become substantially less effective.⁴⁹ This dynamic not only frustrates transparency objectives but also generates uncertainty within real estate markets themselves, undermining public confidence, distorting pricing, and weakening regulatory enforcement.⁵⁰

In light of the above, Delaware's persistent reluctance to adopt robust transparency measures does not only represent a policy disagreement; it raises constitutional concerns by allowing state-level autonomy to frustrate federal objectives aimed at protecting national security and real estate market integrity.

IV. MY OPINIONS AND RECOMMENDATIONS

Based on the analysis done thus far through this Research Paper, my opinion is that effective BOI transparency requires a coordinated approach that addresses both federal and state-level deficiencies. While the CTA represents a significant advancement in US transparency law, its effectiveness depends on complementary state reforms. In my view, meaningful reform must focus on strengthening federal enforcement mechanisms, encouraging state-level alignment, and addressing sector-specific vulnerabilities in real estate markets.

First, Congress and FinCEN should take steps to reinforce the CTA's reporting framework following recent litigation-related disruptions *Texas Top Cop Shop, Inc. v. Garland*. The temporary exemption of US based entities from beneficial ownership reporting underscores the need for clear statutory authority and durable enforcement mechanisms that can withstand judicial scrutiny along with certain contingency plan to manage the outcome caused by such disruptions. Clarifying the scope of FinCEN's authority, enhancing verification procedures, and ensuring timely reinstatement of reporting obligations are essential to maintaining the credibility of the federal transparency regime.

Second, state-level reform, particularly in Delaware is imperative. Such incorporation-friendly jurisdictions with high formation volumes should adopt baseline beneficial ownership disclosure requirements accessible to regulators. Even non-public disclosure/ reporting requirements limited

⁴⁶ *Id.*

⁴⁷ *Id.*, See Arpita Shroff & Diana Pence, *The Mandate of the Corporate Transparency Act*, 142 J. Tax'n 18 (Jan./Feb. 2025), <https://1.next.westlaw.com/Document/I3415e363660311f090a092159c9c2a82/View/FullText.html>

⁴⁸ *U.S. Dep't of the Treasury, National Illicit Finance Strategy 2024*,

<https://home.treasury.gov/system/files/136/2024-Illicit-Finance-Strategy.pdf>

⁴⁹ *Id.*, See Arpita Shroff & Diana Pence, *The Mandate of the Corporate Transparency Act*, 142 J. Tax'n 18 (Jan./Feb. 2025), <https://1.next.westlaw.com/Document/I3415e363660311f090a092159c9c2a82/View/FullText.html>

⁵⁰ *Id.*

towards state level regulatory authorities at the point of formation would be a significant starting point in upholding transparency without undermining legitimate business interests.

Third, expanding on my second recommendation, as evidenced by emerging example of New York's LLC Transparency Act demonstrates a viable path forward. By aligning state-level disclosure requirements with the CTA while incorporating enhanced public access mechanisms, New York illustrates how not just Delaware, but other corporate rich states can reinforce federal objectives. Although the Act has yet to take effect, it reflects growing recognition that corporate transparency is essential not only for financial crime prevention but also for housing market stability and public accountability.

Finally, special attention must be given to real estate markets as a focal point of transparency reform for the obvious reasons discussed throughout this Research Paper. Strengthening transparency in this sector would mitigate the misuse of corporate formation autonomy advantages, deter illicit financial activity, and enhance public trust in property markets.

Considering all the above, these recommendations emphasize on the importance of implementing effective corporate transparency aligning federal and state frameworks for closing transparency gaps, preserving market integrity, and protecting national security.

CONCLUSION

This research paper has examined the growing risks posed by corporate anonymity in US real estate markets through a comparative analysis of the Corporate Transparency Act (CTA) and Delaware's Limited Liability Company Act (DLLCA).⁵¹ It has demonstrated that while federal reforms under the CTA represent a critical step toward beneficial ownership transparency, their effectiveness is undermined by inconsistent state-level disclosure regimes and recent enforcement challenges.⁵²

The analysis underscores that transparency is not merely a compliance mechanism but a foundational safeguard for real estate market integrity and national security.⁵³ Anonymous LLC structures have been repeatedly identified by the US Department of the Treasury and FinCEN as channels for money laundering and sanctions evasion, particularly in high-value real estate transactions.⁵⁴ Without cohesive and enforceable transparency standards across federal and state systems, corporate structures will continue to be exploited for illicit or opaque purposes, frustrating efforts to monitor absentee Beneficial ownership and information.⁵⁵

Considering all of the above, I would like to reiterate that bridging these regulatory gaps is essential to ensuring accountability, deterring financial crime, and maintaining trust in US real

⁵¹ Corporate Transparency Act 31 U.S.C. § 5336(b), https://www.law.cornell.edu/uscode/text/31/5336?utm_source=delcode&utm_medium=delcode&utm_campaign=title6/c018/sc02/index.html, Del. Code Ann. tit. 6, § 18-201, <https://delcode.delaware.gov/title6/c018/sc02/index.html>

⁵² Corporate Transparency Act, 31 U.S.C. § 5336(b) (2021), <https://www.congress.gov/116/plaws/publ283/PLAW-116publ283.pdf>

⁵³ See U.S. Dep't of the Treasury, *National Illicit Finance Strategy 2024*, at 32 (defining safeguarding of property markets as a national security priority), <https://home.treasury.gov/system/files/136/2024-Illicit-Finance-Strategy.pdf>.

⁵⁴ See FinCEN, *Advisory to Financial Institutions and Real Estate Firms on Illicit Finance Risks in the Real Estate Sector*, FIN-2023-A001 (2023), <https://www.fincen.gov>.

⁵⁵ See Jon Lin, *LLCs, Luxury Real Estate, and Secrecy*, N.Y.U. J. Legis. & Pub. Pol'y: Quorum (2023), <https://nyujlpp.org/quorum/ionlin-llcs-luxury-real-estate-secrecy/>.

estate markets and the broader financial system. Meaningful progress in achieving this goal requires harmonizing federal mandates under the CTA with state-level incorporation laws. To begin with, Delaware, the leading state of incorporations, currently impose minimal disclosure obligations. Recent crises being FinCEN's interim final rule and litigation in *Texas Top Cop Shop, Inc. v. Garland*, further adds to the brittleness of federal enforcement when state autonomy remains unchecked. As highlighted above, future reforms could draw on emerging models like New York's LLC Transparency Act, which aligns state disclosure requirements with federal principles while enhancing public access. Therefore, treating beneficial ownership transparency as an immediate priority, rather than a gradual policy aspiration is critical to safeguarding real estate market integrity and reinforcing the effectiveness of national security through prevention of financial crime.

Принятие Цифрового Кодекса РК: от фрагментарного регулирования к системной защите цифровой среды

The Adoption of the Digital Code of the Republic of Kazakhstan: Transition from Fragmented Regulation to Systemic Safeguarding of the Digital Sphere

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Аннотация

В данной статье мной проводится комплексный анализ нормативного закрепления цифровых прав и сопутствующих возникающих проблем правового регулирования их на территории Республики Казахстан. Особую актуальность данная тема получила на фоне принятия Цифрового Кодекса Республики Казахстан от 9 января 2026 года № 255-VIII, а также перехода к модели цифрового государства и повсеместной цифровизации.

Актуальность исследования обусловлена ускоренным развитием цифровой среды и интернета, возрастающим значением цифровых прав человека, а также необходимостью устранения пробелов в законодательстве, которое до 2026 года носило фрагментарный характер.

Целью работы является обзор нормативно-правовой базы Республики Казахстан, выявление проблем законодательного регулирования и оценка эффективности механизмов защиты прав человека после принятия Цифрового Кодекса от 9 января 2026 г. № 255-VIII. В рамках исследования проанализированы международные стандарты (Всеобщая декларация прав человека, резолюции Совета ООН по правам человека), конституционные основы и иерархия нормативных правовых актов РК, а также принципы нового Кодекса (ст. 4–13), включая приоритет прав человека, безопасность, свободу обращения цифровых данных, технологическую нейтральность и цифровую этику.

Annotation

In this article, I conduct a comprehensive analysis of the legal codification of digital rights and the associated challenges of regulating them in the territory of the Republic of Kazakhstan. This topic has become particularly relevant in light of the adoption of the Digital Code of the Republic of Kazakhstan on January 9, 2026, No. 255-VIII, as well as the transition to a digital state model and the widespread digitalization.

The relevance of this study is driven by the accelerated development of the digital environment and the internet, the growing significance of human digital rights, and the need to address gaps in legislation, which until 2026 was fragmentary in nature.

The aim of this work is to review the legal and regulatory framework of the Republic of Kazakhstan, identify issues in legislative regulation, and assess the effectiveness of mechanisms for protecting human rights following the adoption of the Digital Code of January 9, 2026, No. 255-VIII. The study analyzes international standards (the Universal Declaration of Human Rights, United Nations Human Rights Council resolutions), constitutional foundations, and the hierarchy of legal

acts in Kazakhstan, as well as the principles of the new Code (Articles 4–13), including the prioritization of human rights, security, freedom of digital data circulation, technological neutrality, and digital ethics.

Ключевые слова

цифровые права, Цифровой кодекс Республики Казахстан, цифровая среда, защита персональных данных, кибербезопасность, принципы цифрового законодательства, искусственный интеллект, цифровая трансформация, утечки данных, цифровая грамотность, конституционные права в цифровой среде, технологическая нейтральность, цифровая этика.

Key words

rights, Digital Code of the Republic of Kazakhstan, digital environment, personal data protection, cybersecurity, principles of digital legislation, artificial intelligence, digital transformation, data breaches, digital literacy, constitutional rights in digital environment, technological neutrality, digital ethics.

Введение

С конца 20 века постепенно развивалась цифровая среда и интернет в частности, что повлекло зарождение новых прав. Цифровые права с каждым годом приобретали большее влияние и значение для человека, что постепенно привело к возникновению стратегической необходимости урегулирования таких отношений с целью развития общества и повышение суверенности государства. Ранее цифровые права никак законодательно не закреплялись, но принятие Цифрового Кодекса от 9 января 2026 года № 255-VIII стало одной из ключевых ступеней по реализации политики государства, направленной на усиление и повсеместное распространение цифровых технологий и искусственного интеллекта. Целью статьи является обзор нормативно-правовой базы Республики Казахстан, а также поиск и выявление проблем законодательной базы.

На данный момент в научной литературе термин цифровые права ещё не обрёл устоявшегося определения и под ним принято понимать любые права человека, которые могут возникать при взаимодействии с компьютерными технологиями или в интернет-среде. В нормативно правовых акта Республики Казахстан кодексально не закреплено точное определение, в научных кругах правоведов принято перечислять какие права могут относиться к таковым и, ссылаясь на определение из Гражданского Кодекса, выводить свои. В англоязычной литературе можно встретить, когда цифровые права называют «Internet rights» (интернет-права), «right to communicate» (право на коммуникацию) и иные вариации.

В международном праве цифровые права были закреплены во Всеобщей декларации прав человека и резолюции Совета ООН по правам человека. В резолюции 47/23 от 13 июля 2021 года «Новые и появляющиеся цифровые технологии и права человека» акцентировалось необходимость в защите прав человека при использовании новых технологий, таких как интернет-сеть, искусственный интеллект и др., также выдвигались рекомендации по улучшению механизмов сотрудничества Государств и IT-корпораций с целью предотвращения утечек и повышения защиты от них, но со стороны экспертов ООН основной акцент и повышенное внимание было уделено мерам по защите конфиденциальности, цифровой идентификации и опасность онлайн насилия [6].

В 10 статье закона «О правовых актах» приводится иерархия нормативных правовых актов, в которых чётко прописывается первостепенная приоритетность и главенственность и наличие высшей юридической силы Конституции над всеми другими актами [ст. 10, 5]. Однако, на момент написания статьи в Конституции Республики Казахстан от 30 августа 1995

года, при учёте последних изменений и дополнений от 19.09.2022 г., не нашлось ни единого прямого упоминания слов «интернет», «цифровые права» и тд. Стоит отметить, что у нас имеются нормы, которые косвенно относятся к цифровой среде, такие как статья 18, которая защищает частную жизнь и её тайну, статья 20, которая даёт свободу слова и доступ к информации. [ст. 18, 20; 1]. Также отдельные упоминания были в Законе Республики Казахстан «О персональных данных и их защите» от 21 мая 2013 года N 94-V [4]; в Законе Республики Казахстан «Об информатизации» от 24 ноября 2015 года № 418-V [3], однако отсутствовала целостность.

Однако начиная с 2025 года на территории Республики Казахстан постепенно и планомерно начались проводиться действия по созданию отдельного кодекса, который бы смог юридически закрепить данные общественные отношения.

В октября 2025 года на международном форуме Digital Bridge 2025 на конференции Президентом Республики Казахстан Касым-Жомарт Токаевым была изложена стратегия цифрового развития Казахстана. Именно в этом выступлении им было заявлено: «Наша стратегическая цель — превратить Казахстан в полностью цифровое государство в течение трех лет». [10]. Также им было озвучено, что Казахстан разрабатывает Цифровой Кодекс, который в последствии будет служить основой для последовательной цифровизации государства в сферах образования, здравоохранения, экономики и государственного управления

17 октября 2025 года на заседании общественной палаты при мажилисе обсуждался проект данного кодекса. После заседания одним из депутатов мажилиса, а именно членом общественной палаты Екатериной Смышляевой был дан следующий комментарий: «Сегодня в разных отраслях существуют десятки определений цифровой платформы, что создаёт путаницу. Кодекс должен навести порядок и задать единые рамки регулирования». [11].

Далее на пленарном заседании Мажилиса Парламента РК 12 ноября 2025 года в первом чтении одобрен проект Цифрового кодекса. После уже 25 декабря 2025 года Сенат одобрил проект Цифрового Кодекса.

И вот уже 9 января 2026 года Президентом Республики Казахстан был подписан Цифровой Кодекс № 255-VIII, который закрепил основные принципы, цифровые объекты, предметы и их продукты, субъектов цифровой среды, компетенции государственных органов и тд.

При ознакомлении с законом очень важно понимать принципы, на которых он базируется. Далее я привожу таблицу, в которой я перечисляю принципы Цифрового Кодекса Республики Казахстан, которые были указаны в статье 4 и провожу трактовку, данную нам из последующих статей [ст. 5 – 13; 2].

№	Принцип	Трактование принципа, его содержание
1	Соблюдение прав, свобод и законных интересов человека в цифровой среде	Права, свободы и законные интересы человека признаются наивысшей ценностью; какое-либо ограничение не допускается
2	Безопасность человека, общества и государства при применении цифровых технологий	Безопасность человека, общества и государства при применении цифровых технологий являются неотъемлемым элементом устойчивого развития цифровой среды; Государство принимает меры по предупреждению и снижению рисков негативного воздействия технологий на права, свободы и интересы граждан, общества и государства
3	Свобода обращения цифровых данных	В Республике Казахстан обеспечивается свобода поиска, формирования, передачи, хранения и использования цифровых данных; Государство содействует развитию открытости, доверенности, доступности, актуальности и полноты цифровых данных
4	Свобода создания, развития и применения цифровых технологий	Создание, развитие и применение цифровых технологий осуществляются свободно; государство создаёт условия для проведения научных исследований, инновационной деятельности и развития цифровых технологий
5	Баланс частных и публичных интересов	Регулирование общественных отношений в цифровой среде осуществляется с соблюдением баланса между частными и публичными интересами
6	Доступность и инклюзивность цифровой среды	Государство обеспечивает равный доступ граждан к цифровым технологиям, продуктам, услугам и возможностям в цифровой среде; Цифровые объекты разрабатываются и используются с учётом доступности для лиц с инвалидностью и иных маломобильных групп населения

7	Пропорциональное и обоснованное участие государства в цифровой среде	Государство участвует в цифровой среде в пределах НПА РК; Государственное участие в создании и эксплуатации цифровых ресурсов и систем допускается для реализации государственных функций, оказания государственных услуг и обеспечения безопасности, устойчивости и доступности цифровой инфраструктуры при недопущении необоснованного вмешательства в конкурентную среду
8	Технологическая нейтральность правового регулирования	Принцип технологической нейтральности правового регулирования предполагает равное отношение к разным цифровым технологиям, а правовое регулирование осуществляется исходя из функциональных характеристик; Государство обеспечивает предсказуемость и стабильность правового регулирования при появлении новых цифровых технологий, не создавая препятствий для их развития
9	Цифровая этика и социальная ответственность	Создание, развитие и применение цифровых технологий осуществляется с соблюдением принципов уважения прав и достоинств человека, недопустимости дискриминации, справедливости, добросовестности, прозрачности и ответственности; Государство, организации и граждане участвуют в формировании и соблюдении этических стандартов поведения в цифровой среде, направленных на предотвращение дискриминации, манипуляции, злоупотребления цифровыми технологиями и иных нарушений прав, свобод и законных интересов человека, общества и государства

Таблица 1. Основные принципы цифрового законодательства Республики Казахстан

Несмотря на важность принятия данного кодекса и весь прогресс, что он превознёс в правовую и законотворческую среду Республики Казахстан, всё так же остаются существенные вызовы в данной сфере.

Одной из самых больших проблем является недостаточная эффективность механизмов защиты данных. В 2024 году АО «Государственная техническая служба» (ГТС) Казахстана опубликовала статистические данные, в которых говорилось о наличии свыше 41 000 инцидентов информационной безопасности, что является ростом в 2,6 раза по сравнению с 2023 г. Также в своём отчёте были озвучены следующие цифры [8]:

- 41,000+ инцидентов информационной безопасности
- 21,940 случаев заражения вредоносным ПО
- 66 млн мошеннических звонков предотвращено в Q1 2025
- 78-е место в глобальном индексе кибербезопасности

По статистическим данным МВД РК в 2025 г. количество киберпреступлений увеличилось на 86,1 % за 10 месяцев [7].

Показатель	2023 г.	2024 г.	2025 г.	Рост в %
Инциденты информационной безопасности (ГТС)	15 770 +	41 000 +	43 крупных утечек данных	≈ +86,1 %
Крупнейшая утечка	-	9 млн.	16.3 млн	≈ +81 %.
Киберпреступления (по данным МВД)	11 000 +	15 905 дел	22 000 +	≈ +41 % в год
Раскрываемость	~27%	28,4%	38, 9%	≈ +44 %

Таблица 2. Статистика киберинцидентов и утечек персональных данных в Республике Казахстан (2024–2025 гг.) [7] [8] [9]

В данной таблице приведены числа, полученные из официальных источников. Ярким примером недостаточной эффективности законодательства является утечка баз данных с информацией на 16,3 млн граждан. В этих данных хранились ИИН, телефоны, адреса граждан и злоумышленники получили ко всей этой информации беспрепятственный доступ. Отсутствие достаточно контроля за операторами связи, отсутствие соразмерного наказания за подобные нарушения, а также низкая цифровая грамотность самих граждан в совокупности привели к данному инциденту.

Несмотря на принятие указанного Кодекса, анализ статистических тенденций свидетельствует о сохраняющейся структурной неэффективности механизмов государственного надзора и ответственности в сфере обработки персональных данных. Отсутствие обязательных требований к внедрению многоуровневых систем криптографической защиты и регулярных независимых аудитов у операторов критической информационной инфраструктуры приводит к тому, что даже выявленные инциденты зачастую не влекут за собой адекватных мер по устранению уязвимостей. В результате, как демонстрирует динамика утечек (с 9 млн записей в 2024 г. до 16,3 млн в 2025 г.), происходит не только количественный рост инцидентов, но и качественное усложнение угроз: переход от случайных заражений вредоносным ПО к целенаправленным атакам на государственные и коммерческие базы данных.

Заключение

Принятие Цифрового Кодекса Республики Казахстан № 255-VIII от 9 января 2026 г. стало знаковым этапом в развитии национального законодательства, впервые консолидировав на уровне кодифицированного акта принципы регулирования общественных отношений в цифровой среде. Закрепление девяти базовых принципов (от приоритета прав человека до технологической нейтральности и цифровой этики) создало системную основу для реализации стратегии «полностью цифрового государства»,

озвученной Президентом РК на форуме Digital Bridge 2025. Кодекс устранил ранее существовавшую фрагментарность правового регулирования, обеспечил единые терминологические рамки и заложил механизмы баланса частных и публичных интересов.

Вместе с тем проведённый анализ выявил существенные ограничения действующего правового инструментария. Несмотря на рост раскрываемости киберпреступлений (с 27 % в 2023 г. до 38,9 % в 2025 г.), абсолютные показатели инцидентов информационной безопасности и масштабы утечек персональных данных (16,3 млн граждан) свидетельствуют о недостаточной эффективности превентивных и охранительных механизмов. Отсутствие детализированных норм ответственности операторов связи, слабый контроль за соблюдением требований к защите данных и низкая цифровая грамотность населения продолжают создавать критические риски нарушения конституционных прав (ст. 18, 20 Конституции РК).

Таким образом, Цифровой Кодекс представляет собой необходимую, но недостаточную меру. Для достижения заявленной цели превращения Казахстана в цифровое государство в течение трёх лет требуется комплексное развитие подзаконных актов, усиление административной и уголовной ответственности, внедрение международно-признанных стандартов кибербезопасности (в том числе в рамках сотрудничества с ООН и IT-корпорациями) и системная программа повышения цифровой грамотности населения. Только при условии решения указанных проблем новый Кодекс сможет в полной мере выполнить функцию не только регулятора, но и гаранта устойчивого и безопасного развития цифровой среды Республики Казахстан. Дальнейшие исследования должны быть направлены на эмпирическую оценку правоприменительной практики и разработку конкретных законодательных поправок, обеспечивающих реальную защиту цифровых прав граждан.

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Medical Sciences

Нутритивная недостаточность у больных раком желудка в пост операционном периоде: современные аспекты патогенеза, диагностики и коррекции (литературный обзор)

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Рак желудка (РЖ) остается одной из наиболее серьезных проблем современной онкологии, стабильно занимая лидирующие позиции в структуре мировой онкологической заболеваемости и смертности. Несмотря на совершенствование хирургических техник и протоколов комбинированного лечения, ключевым фактором, определяющим прогноз и выживаемость пациентов, остается их нутритивный статус.

В Республике Казахстан РЖ стабильно занимает 4-е место в структуре онкологической заболеваемости и 2-е место по показателям смертности. Согласно данным главного внештатного онколога МЗ РК, академика Д. Р. Кайдаровой, по итогам 9 месяцев 2024 года в стране было зарегистрировано 30 744 первичных пациента (показатель заболеваемости — 203,8 на 100 000 населения)[1,2].

Наблюдается небольшое снижение заболеваемости с 7,7% в 2020 году до 7,0% в 2024 году[1].

Наиболее высокие показатели заболеваемости на 100 000 населения зафиксированы в Карагандинской (267 случаев), Костанайской (165 случаев) и Западно-Казахстанской областях (141 случай).

Низкая пятилетняя выживаемость (около 17,1%) во многом обусловлена поздней диагностикой — 33,5% случаев выявляются на III стадии, а значительная часть пациентов имеет тяжелую нутритивную недостаточность уже на момент постановки диагноза [2].

В современной онкологии частичное или тотальное удаление желудка с лимфодиссекцией остается единственным радикальным методом лечения злокачественных новообразований желудка [3]. По современным представлениям в клинической практике утвердилось 3 основных вида операций в лечении рака желудка — гастрэктомия, субтотальная проксимальная и субтотальная дистальная резекции желудка. Если опухоль локализована в теле желудка или имеет инфильтративный рост и тотальное поражение

желудка выполняется оперативное вмешательство в объеме гастрэктомии [4,5]. В настоящее время, предложенная японскими исследователями, тактика стандартной радикальной резекции желудка и гастрэктомии с D2-лимфодиссекцией, считается общепринятым в онкологии золотым стандартом лечения [6].

В практической онкологии Казахстана гастрэктомия является одной из основных операций в арсенале хирургического лечения РЖ и составляет до 70% всех радикальных операций [7-10].

Существует проблема в протекании раннего и позднего реабилитационного периода, связанная с развитием органических и функциональных нарушений оперированного желудка. М.И. Давыдов и соавторы исследовали поздние результаты гастрэктомии и трактовали, что проблема постгастрэктомического синдрома, которая возникает вследствие отсутствия желудка до сих пор не теряет свою актуальность [11]. При анализе исследовательских работ относительно последствий гастрэктомий выявлено, что отечественные и зарубежные исследователи изучают данную проблему не только как хирургическую, но и патофизиологическую [12, 13].

Нутритивная недостаточность (или синдром мальнутриции) после резекции желудка – это патологическое состояние, характеризующееся недостатком макро- и микронутриентов, возникающее вследствие нарушения процессов переваривания и всасывания пищи. В патогенезе нутритивной недостаточности ведущим считается синдром анорексии–кахексии. При локализации опухоли в верхнем отделе желудочно-кишечного тракта синдром кахексии наблюдается у 80% [14].

В патогенезе анорексии большое значение отводят нарушению систем, ответственных за аппетит: лептиново-грелиновой регуляции, аберрантной передаче сигналов, нарушению нейропептид Y-регуляции гормонов и ряда аминокислот, высвобождение опухолью специальных субстанций: липид и протеин мобилизирующих факторов. Важным в развитии анорексии считают нарушение в системе лептин–грелин [15,16].

Известно, что объем новообразования не является критерием развития кахексии. Наиболее важна локализация опухоли, особенно при поражении гастроинтестинального тракта [17]

Современная онкохирургия переходит от концепции чисто радикального удаления опухоли к стратегии достижения максимальной выживаемости при сохранении высокого качества жизни (Quality of life, QoL). Как отмечают J. Kim и H.J.Lee (2025) функционально сохраняющие операции (такие как проксимальная резекция или пилоросохраняющая гастрэктомия) направлены на минимизацию постгастрэктомического синдрома, который является основной причиной глубокой нутритивной недостаточности и социальной дезадаптации в послеоперационном периоде [18]. Актуальность данной проблемы обусловлена тем, что сохранение даже части желудка позволяет поддерживать физиологический пассаж пищи и секреторную активность, что критически важно для предотвращения отдаленных нутритивных потерь. В связи с этим, выбор объема операции и метода реконструкции ЖКТ становится стратегически важным. Актуальные исследования (Song J. H. et al., 2025) демонстрируют, что орган сберегающие подходы, такие как проксимальная резекция желудка, позволяют существенно снизить частоту анемии и дефицита витамина B12 по сравнению с тотальной гастрэктомией, обеспечивая лучший нутритивный прогноз [19,20,21]. Таким образом, комплексный анализ и своевременная коррекция нутритивного статуса являются необходимым условием успешной реабилитации больных раком желудка.

Согласно мета-анализу нутритивная недостаточность (Finze A. et al., 2024), и сопутствующие ей витаминные дефициты (особенно железа и белки) ведут к значительному

росту осложнениям:

- Несостоятельность анастомозов. Дефицит белка и микроэлементов нарушает синтез коллагена и ангиогенез в зоне хирургического шва, что является основной причиной тяжелых перитонитов.

- Инфекционные осложнения: НН вызывает вторичный иммунодефицит. Снижение числа лимфоцитов и уровня альбумина коррелирует с высокой частотой послеоперационных пневмоний и нагноении раны.

- Нарушение регенерации: Как отмечается в работе Muszynski T. (2024), низкий фазовый угол является маркером клеточного истощения, что замедляет общее восстановление организма после агрессивного вмешательства [22].

Пациенты с выраженной НН требуют более длительного пребывания в отделении интенсивной терапии и стационаре:

- Замедленное восстановление моторики ЖКТ (парезы)
- Необходимость в дорогостоящем парентеральном питании и антибактериальной терапии при возникновении осложнений.

- Средняя длительность госпитализации у пациентов с НН на 30-50% выше, чем у пациентов с сохранным нутритивным статусом.

Наиболее долгосрочное влияние НН оказывает на онкологические результаты:

- Снижение общей выживаемости: Исследования подчеркивает (Song J. H. et al., 2025), что сохранение нутритивного статуса и предотвращение анемии после операции (например, при выполнении проксимальной резекции) ассоциировано с лучшими показателями долгосрочной выживаемости [21].

В отличие от алиментарного голодания, при котором организм адаптируется путем снижения интенсивности метаболизма, раковая кахексия характеризуется гиперметаболизмом и потерей скелетной мускулатуры (саркопенией), часто протекающей на фоне сохранения или даже увеличения жировой массы. Саркопения становится независимым прогностическим фактором, коррелирующим с ростом послеоперационных осложнений и плохой переносимостью химиотерапии. Механизм её развития связан с системным воспалением, которое запускает протеолиз и снижает чувствительность гипоталамических центров к сигналам насыщения, что ведет к анорексии и прогрессирующему истощению [23,22].

Хирургическое вмешательство, являясь золотым стандартом лечения, накладывает на пациента значительную метаболическую нагрузку. После гастрэктомии или обширной резекции утрачиваются критические функции желудка:

- Резервуарная функция: Утрата емкости ограничивает разовый прием пищи, запуская первичный дефицит калорий.

- Секреторная функция: Ахлоргидрия (отсутствие соляной кислоты) делает невозможной адекватную денатурацию белков и перевод микроэлементов, таких как железо и кальций, в растворимую, усвояемую форму.

- Нейроэндокринная функция: Удаление основного органа-продуцента грелина (гормона голода) приводит к падению его уровня в плазме на 70-80% без последующего восстановления в течение многих лет.

Динамика основных показателей РЖ в Казахстане (2020-2024 гг.)

Показатель	2020 г.	2023 г.	2024 г. (прогноз)
Заболеваемость (%)	7,7	6,9	7,0
Смертность (позиция)	2-е место	2-е место	2-е место
Первичные пациенты (абс.)	-	-	30 744 (за 9 мес.)
Раннее выявление (стадия I)	-	63,1 (тенденция)	-

Традиционные методы оценки, такие как индекс массы тела (ИМТ), в современной онкологии подвергаются серьезной критике. ИМТ не способен выявить «саркопеническое ожирение» — состояние, при котором критическая потеря мышечной массы скрывается за избыточным весом. В работах В. К. Лядова и Д. С. Федоринова (2024) подчеркивается, что саркопения выявляется у 40% пациентов даже при нормальном ИМТ, что делает необходимым использование инструментальных методов оценки [23].

Биоимпедансный анализ состава тела (БИА) позволяет объективизировать потерю мышечной и жировой массы. Ключевым параметром в этом контексте является фазовый угол, который рассчитывается на основе реактивного (X_c) и активного (R) сопротивления тканей:

Фазовый угол служит прямым индикатором клеточной целостности и мембранного здоровья. Низкий фазовый угол является маркером клеточного истощения и независимым предиктором неблагоприятного исхода. Исследование Muszynski T. и соавт. (2024) на группе из 248 пациентов показало, что снижение фазового угла на 1 градус достоверно ассоциировано с восьмикратным увеличением риска развития тяжелой мальнотриции по критериям GLIM[22].

Сравнительные характеристики фазового угла для скрининга саркопении

Группа пациентов	Пороговое значение (муж)	Пороговое значение (женщины)	Чувствительность
Рак желудка	4,6°	4,3° (общий тренд)	0.795 - 0.814
ХОБЛ	4,75°	-	0.78
Пожилые женщины (риск падений)	-	≤ 4,1°	-
Сердечно-сосудистые заболевания	4,55°	4,25°	-

Для выявления рисков заболевания существуют Скрининговые шкалы и проводится метаболический мониторинг.

Шкала NRS-2002 признана «золотым стандартом» для первичного выявления риска у 92% пациентов. Однако для более глубокой оценки в онкологии используется анамнестическая субъективная глобальная оценка (ASG-SFW), которая учитывает специфические симптомы: анорексию, депрессию и болевой синдром.

Лабораторная диагностика фокусируется на уровне преальбумина как на чувствительном маркере нутритивных изменений в реальном времени (период полураспада 2 дня) по сравнению с традиционным, но инертным альбумином. Б. С. Жолдыбай (2024) указывает на замедленное восстановление преальбумина именно после тотальной гастрэктомии, что диктует необходимость более агрессивной нутритивной поддержки в этой группе[25].

В последние годы в онкохирургии желудка происходит смена парадигмы в сторону функционально-сохраняющих вмешательств. Основная цель таких операций — минимизация постгастрэктомического синдрома и сохранение адекватного качества жизни.

Традиционно при опухолях верхней трети желудка выполнялась тотальная гастрэктомия (ТГ). Однако результаты пятилетнего наблюдения (Song J. H. et al., 2025) показывают, что проксимальная резекция (ПР) обеспечивает лучший нутритивный прогноз. Сохранение дистальной части желудка (секреция гастрина) позволяет поддерживать более высокие уровни гемоглобина и витамина В12 за счет сохранения части париетальных клеток и физиологического пассажа через двенадцатиперстную кишку[20,21,26].

Согласно данным Song J. H. (2025), в группе ПР средняя потеря веса через 12 месяцев составляет 6,9 кг, в то время как в группе ТГ этот показатель достигает 17,9 кг. Проксимальная гастрэктомия (ПГ) позволяет минимизировать риск рефлюкс-эзофагита.

Сравнительные исходы хирургических методов (12 месяцев после операции)

Параметр исхода	Проксимальная резекция (ПР)	Тотальная гастрэктомия (ТГ)	P-value
Потеря веса (кг)	6,9 ± 5,2	17,9 ± 4,0	<0.001
Уровень альбумина (г/дл)	3,8 ± 0,6	2,9 ± 0,6	<0.001
Дефицит витамина В12	Значительно ниже	Высокий (>55%)	<0.001
Рефлюкс-эзофагит (%)	6,5	14,7	0.085
5-летняя выживаемость	54,8%	47,8%	-

Пилоросохраняющая гастрэктомия.

Для опухолей средней трети желудка в стадиях cT1N0 альтернативой стандартной дистальной резекции выступает пилоросохраняющая гастрэктомия. Сохранение привратника предотвращает развитие демпинг-синдрома и дуоденогастрального рефлюкса, а также способствует лучшему поддержанию массы тела в долгосрочном периоде. Тем не менее, этот метод требует высокой хирургической квалификации для сохранения иннервации и кровоснабжения пилорического отдела.

В работах С.В. Обухова (2024) подчеркивается, что нутритивная недостаточность у больных раком желудка является не статичным состоянием, а динамическим процессом, имеющим свои критические точки в раннем и отдаленном послеоперационном периоде. Он указывает на необходимость комплексного мониторинга, который включает не только биохимические показатели, но и оценку состава тела. Обухов С. В. выделяет «метаболическую цену» операции, которая проявляется в отрицательном азотистом балансе и быстрой потере висцерального пула белков в первые 10-14 дней после гастрэктомии [19,26]. Интегрируя исследования многих авторов, можно выделить следующие этапы метаболической деградации:

На раннем этапе (до 3 месяцев): доминирует белково-энергетическая недостаточность. Обухов С.В. акцентирует внимание на том, что без ранней нутритивной поддержки (сипинга) потеря веса в этот период может стать необратимой, запускаются механизмы кахексии.

На промежуточном этапе (6-12 месяцев): проявляется последствия мальабсорбции микронутриентов. В это время манифестирует дефицит железа и витамина В12, что Обухов С.В. связывает с перестройкой секреторной функции оставшихся отделов ЖКТ

На отдаленном этапе (более 2 лет): На первый план выходят нарушения костного метаболизма. В то время как отечественные авторы указывают на общую минеральную

недостаточность, L.A. Gambi (2023) детально описывает риск остеопоротических переломов после тотальной гастрэктомии из-за вторичного гиперпаратиреоза, вызванного дефицитом витамина Д. Исследование S.Park(2024) показало, что при тотальной гастрэктомии дефицит витамина Д встречается значительно чаще, чем при субтотальной резекции.

Синдром "малого желудка", демпинг-синдром- обусловлен резким сокращением объёма анатомического или сформированного (из тонкой кишки) резервуара. Демпинг-синдром является более тяжелым функциональным нарушением, возникающим из-за быстрой эвакуации гиперосмолярного содержимого (химуса) из культи желудка или пищевода непосредственно в тонкую кишку[26,27].

Ранний демпинг-синдром (через 15-30 мин после еды): быстрый сброс химуса вызывает перемещение жидкости из сосудистого русла в просвет кишки. Это приводит к резкому растяжению кишки и выбросу вазоактивных пептидов. Пациент испытывает слабость, головокружение, потливость и сердцебиение.

Поздний демпинг-синдром (через 1,5-3 часа после еды): обусловлен избыточным выбросом инсулина в ответ на быстрое всасывание глюкозы, что приводит к реактивной гипогликемии. Как это влияет на потерю веса? Пациенты начинают ассоциировать прием пищи с тяжелыми вегетативными кризами, что приводит к сознательному и подсознательному отказу от еды. Сверхбыстрый транзит пищи не позволяет пищеварительным ферментам и желчи адекватно перемешаться с химусом, что резко снижает эффективность всасывания жиров и белков.

Синдром малого желудка и демпинг-синдром формируют патологический паттерн питания, при котором дефицит калорий усугубляется страхом пациента перед приемом пищи. Как указывает Обухов С.В, без своевременной медикаментозной коррекции и подбора специализированных смесей (сипинга) эти состояния ведут к развитию необратимой стадии кахексии. Таким образом, функционально-сохраняющая хирургия должна рассматриваться как основной метод профилактической тяжелой послеоперационной потери веса.

Удаление желудка или его значительной части приводит к «выключению» ключевых звеньев всасывания нутриентов. Согласно мета-анализу риск развития дефицитов сохраняется пожизненно, а их распространенность достигает 50-90% в зависимости от нутриента.

Закономерным последствием гастрэктомии является дефицит витамина В12 (кобаламина). Удаление фундального отдела желудка ведет к исчезновению париетальных клеток, продуцирующих внутренний фактор Касла. Без него всасывание витамина В12 в подвздошной кишке становится практически невозможным. После тотальной гастрэктомии дефицит манифестирует через 2-3 года (после истощения запасов в печени), в то время как проксимальная резекция позволяет сохранить часть секреторной функции и снизить риск мегалобластной анемии. В последствии возникает пернициозная анемия, фуникулярный миелоз (неврологические нарушения), когнитивные расстройства [22].

Также в постоперационном периоде у пациентов наблюдается дефицит железа и железодефицитная анемия. Желудочный сок (соляная кислота) необходим для солиubilизации железа и его перехода из трехвалентной формы в двухвалентную. Кроме того, реконструкция по Ру исключает пассажа двенадцатиперстную кишку-основную зону абсорбции железа. Дефицит железа является самым ранним маркером нутритивной недостаточности, развиваясь у 45-55% пациентов уже в первый год после операции.

Еще одним последствием являются нарушение обмена кальция и витамина Д. Мальабсорбция жиров (из-за билиопанкреатической асхроний) ведет к потере жирорастворимого витамина Д, что вызывает вторичный гиперпаратиреоз: организм

«вымывает» кальций из костей для поддержания его уровня в крови. Резкое снижение минеральной плотности костей и высокий риск остеопоротических переломов (особенно шейка бедра) в отдаленном периоде (через 5+лет)[20,28]

Дефицит других нутриентов как фолиевая кислота (B9) часто сопутствует дефициту B12, усугубляя анемию. Дефицит жирорастворимых витаминов (A,E,K) обусловлен стеатореей (плохим перевариванием жиров). Дефицит цинка и меди ведет к снижению иммунного статуса и замедляет заживление тканей

Отсутствие внутреннего фактора Касла после гастрэктомии делает всасывание витамина B12 практически невозможным. Дефицит обычно манифестирует через 2–3 года после истощения депо в печени, приводя к мегалобластной анемии и неврологическим нарушениям (фуникулярному миелозу). Железодефицитная анемия развивается еще раньше — у 45–55% пациентов в первый год — из-за отсутствия соляной кислоты и обхода двенадцатиперстной кишки при реконструкции по Ру.

Динамика костной плотности после различных типов операций (5 лет)

Тип операции	Степень снижения	Частота переломов (%)	Корреляция
Тотальная гастрэктомия	Максимальное снижение	Высокая (~20%)	Значимая
Дистальная резекция	Умеренное снижение	Средняя	-
Проксимальная резекция	Минимальное снижение	Низкая	-
Эндоскопическая резекция	-1,52% - -3,30%	Очень низкая	-

Интеграция нутритивной поддержки в раннем и позднем постоперационном периоде является обязательным условием успешной реабилитации. Основная цель предоперационного этапа (пререабилитации) — перевод пациента из катаболического состояния в анаболическое.

Научно обоснованные рекомендации по питанию и персонализированная диетотерапия при онкологических заболеваниях являются важным компонентом лечебно-профилактических мероприятий, играющих существенную роль в поддержании массы тела, сохранении энергетических и пластических запасов организма, устранении или снижении выраженности симптомов недостаточности питания, улучшении качества жизни пациента [29]. Персонализированная нутритивная поддержка обеспечивает полноценное питание онкологических больных за счет применения в комплексе лечебных мероприятий [30,31].

Авторами отмечается, что лечебное питание, адекватное энергетическим и пластическим потребностям организма, необходимо применять на всех стадиях заболевания с целью улучшения клинического течения, прогноза и качества жизни пациентов, подлежащих противоопухолевой терапии [31,32].

Применение иммунного питания, обогащенного аргинином, омега-3 жирными кислотами и нуклеотидами, за 5–7 дней до операции позволяет снизить частоту инфекционных осложнений на 30–50% и сократить длительность госпитализации. Аргинин критически важен для синтеза коллагена в зоне анастомоза, а омега-3 кислоты модулируют системный воспалительный ответ.

Согласно мета-анализу Finze A. (2024), несмотря на существенную гетерогенность данных, индивидуально подобранная нутритивная поддержка демонстрирует неоспоримые преимущества в клинических исходах. Использование пероральных нутритивных добавок в течение 3 месяцев после выписки достоверно снижает потерю веса и улучшает приверженность к адъювантной химиотерапии.

Парентеральное питание (ПП) остается методом выбора при невозможности

использования ЖКТ, например, при несостоятельности анастомозов или тяжелом парезе кишечника более 5 суток. Современные системы «три в одном», содержащие аминокислоты, глюкозу и жировые эмульсии нового поколения, позволяют сбалансировать нутритивный вклад при минимальном риске инфекционных осложнений. Однако ПП требует жесткого контроля гликемии и электролитного баланса для предотвращения рефидинг-синдрома у истощенных больных.

Эффективная коррекция НН невозможна без участия мультидисциплинарной команды, включающей онкохирурга, химиотерапевта, диетолога и реабилитолога. Данные показывают, что мультидисциплинарный-подход позволяет улучшить показатели качества жизни и сократить частоту неплановых повторных госпитализаций.

Будущее нутритивной онкологии связано с:

- Цифровыми интервенциями: Дистанционный мониторинг веса и симптомов пациента.
- Персонализированной нутригеномикой: Подбор микронутриентов на основе генетического профиля опухоли и пациента.
- Фармакологической поддержкой: Использование агонистов рецепторов грелина для стимуляции аппетита и анаболизма.

Заключение

Нутритивная недостаточность при раке желудка является системным процессом, который начинается задолго до хирургического вмешательства и продолжается в течение многих лет после него. Современные стратегии лечения должны базироваться на ранней инструментальной диагностике саркопении с использованием биоимпедансного анализа и мониторинга фазового угла. Функционально-сохраняющая хирургия, такая как проксимальная резекция с двойным трактом, должна рассматриваться как приоритетный метод лечения ранних форм РЖ верхней трети, учитывая её доказанные нутритивные преимущества.

Пожизненный мониторинг микронутриентного статуса, здоровья костной ткани и адекватная нутритивная поддержка (включая иммунное питание и длительное использование пероральных нутритивных добавок) являются неотъемлемыми компонентами радикального лечения, превращая «выживаемость» в полноценное «качество жизни». Мультидисциплинарная интеграция нутритивного менеджмента в клиническую практику является ключевым резервом снижения послеоперационной смертности и улучшения отдаленных результатов лечения больных раком желудка.

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PSYCHOEMOTIONAL STATE OF PREGNANT WOMEN WITH PREECLAMPSIA AND ITS IMPACT ON THE COURSE OF PREGNANCY

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Preeclampsia is one of the most significant complications of pregnancy and remains a pressing issue in modern obstetrics due to the high risk of maternal and perinatal morbidity and mortality. Despite significant advances in diagnosis and treatment, the incidence of this condition remains consistently high, necessitating further study of the risk factors and mechanisms of its development. In recent years, particular attention has been paid to the psychoemotional state of pregnant women as a potentially significant factor influencing the course of pregnancy. Pregnancy is accompanied by significant hormonal and psychophysiological changes that contribute to increased vulnerability to stress, anxiety, and depressive disorders. Accumulated evidence suggests that psychoemotional disturbances can influence the neuroendocrine and vascular mechanisms underlying the development of preeclampsia. Modern research demonstrates a relationship between the level of stress, anxiety, and depression in pregnant women and the risk of hypertensive complications. Furthermore, psychoemotional factors can influence the severity of preeclampsia, pregnancy outcomes, and patient adherence to treatment. However, the role of psychoemotional state in the pathogenesis and clinical course of preeclampsia remains poorly understood and requires further scientific analysis. Therefore, research into the psychoemotional state of pregnant women with preeclampsia and its impact on pregnancy is a relevant area of modern medical science and practice.

Preeclampsia remains one of the most significant complications of pregnancy, associated with a high incidence of maternal and perinatal morbidity. In recent years, increasing attention has been paid to the role of psychoemotional factors in its development and course. Modern research demonstrates that anxiety, stress, and depressive disorders are not only widespread among pregnant women but can also be significant risk factors for adverse obstetric outcomes [1].

Pregnancy is a period of increased psychological vulnerability due to hormonal changes, social adaptation, and the anticipation of childbirth. According to modern data, women at increased risk of preeclampsia have significantly higher levels of psychoemotional stress compared to pregnant women with a normal pregnancy [1]. Moreover, stress is often accompanied by severe anxiety and depressive symptoms, creating a complex psychoemotional disorder [2].

A number of recent studies confirm a direct link between psychoemotional disturbances and the development of preeclampsia. High levels of anxiety and depression have been associated

with an increased risk of hypertensive disorders of pregnancy [2, 3]. Moreover, in women with diagnosed preeclampsia, psychoemotional disturbances are more pronounced and can exacerbate the clinical course of the disease [2].

Neuroendocrine mechanisms play a key role in this process. Chronic stress leads to activation of the hypothalamic-pituitary-adrenal axis, which is accompanied by increased levels of cortisol and other stress-associated hormones [4]. This, in turn, can contribute to the development of endothelial dysfunction, impaired vascular tone, and activation of inflammatory processes underlying the pathogenesis of preeclampsia [5]. Thus, psychoemotional factors influence not only the behavioral but also the biological mechanisms of disease development.

Modern research also highlights the significant influence of psychoemotional state on pregnancy outcomes. High levels of stress, anxiety, and depression have been shown to be associated with an increased risk of preterm birth, intrauterine growth retardation, and low birth weight [6, 7]. Furthermore, psychoemotional disturbances can exacerbate existing complications, including preeclampsia, and worsen the mother's overall well-being.

The impact of psychological factors on the quality of life of pregnant women deserves special attention. High levels of anxiety and low psychological resilience have been shown to be associated with poorer overall well-being, decreased adaptive capacity, and increased levels of depressive symptoms [8]. These factors may indirectly impact the course of pregnancy through decreased adherence to treatment and medical recommendations.

Despite significant progress in the study of this issue, many aspects remain understudied. In particular, further study is needed to understand the mechanisms by which psychoemotional and somatic factors interact in the development of preeclampsia, as well as the development of effective methods for prevention and psychological intervention.

Thus, our analysis of modern scientific literature demonstrates the significant role of psychoemotional factors in the development and course of preeclampsia. It has been established that pregnant women with this complication are characterized by higher levels of anxiety, stress, and depressive symptoms compared to women with normal pregnancies.

Psychoemotional disturbances influence both behavioral and biological mechanisms, including neuroendocrine regulation, vascular tone, and inflammatory processes, which can contribute to disease progression. Furthermore, high levels of stress and anxiety are associated with adverse perinatal outcomes, such as preterm birth and low birth weight.

These findings support the need for a comprehensive approach to pregnancy management, including not only medical but also psychological components. The introduction of methods for the early diagnosis of psychoemotional disturbances, as well as the development of psychological support programs, can help reduce the incidence of pregnancy complications and improve pregnancy outcomes.

Further research in this area is necessary to clarify the mechanisms of interaction between psychoemotional and somatic factors and to develop effective preventive strategies.

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OVARIAN CANCER: TOPICAL ISSUES AND THEIR SOLUTIONS

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Annotation: This scientific and analytical work presents modern world and local-regional data on incidence, mortality, lethality and five-year survival rate of such a common oncological pathology as ovarian cancer. The issues of etiology and pathogenesis, modern approaches and principles of complex diagnostics, prospects for improving treatment results, as well as the prognosis are covered in detail. The epidemiological characteristics of this pathology in our republic are given in the context of the regions of the country.

Key words: oncology, gynecology, ovarian cancer, biomarkers, cancer antigen 125, human epididymis protein 4, BRCA1/2 mutation, DNA, RNA, epidemiology, incidence, mortality, lethality, five-year survival rate, prognosis.

Ovarian cancer (OC) is a malignant tumor that most often develops from the ovarian epithelium. Requirements for the pathomorphological conclusion in OC: 1) macroscopic description of the specimen separately for each ovary [size and weight, color, capsule condition, cross-sectional view, approximate ratio of cystic and solid components (in %), presence of papillary structures (if any, in % approximately), and other involved organs]; 2) tumor [total size (3 dimensions: height, width, length), location, type, invasion depth (in relation to the myometrium/endometrium border), myometrium thickness (mm), endometrium, involvement of

the serous membrane of the uterus, involvement of the cervix, appendages)); 3) other findings (presence of invasion into other organs); 4) lymph nodes (if present: size, location, size of the largest lymph node, number, number of cassettes); 5) microscopic description [primary tumor: histologic type, degree of differentiation, invasion, capsule/surface involvement, lymphovascular invasion, immunohistochemical (IHC) markers, metastases (preferably described separately): location of metastases (lymph nodes involved/number of nodes, size of largest metastasis, extension beyond lymph node)] [1].

The diagnostic criteria are as follows. Complaints and anamnesis: all patients are recommended to have a thorough collection of complaints and anamnesis; in the early stages, OC may be asymptomatic or cause minor discomfort; in the advanced stage, the disease manifests itself with non-specific symptoms: an increase in abdominal volume, dyspeptic symptoms, weight loss, loss of appetite, pain in the abdomen or pelvis, shortness of breath, general weakness. The level of evidence for recommendations is A (the level of evidence is 1). Comment: collecting information about complaints and anamnesis details, including family history, is carried out in order to identify factors that may influence the choice of treatment tactics.

Physical examination: a thorough physical examination is recommended; it includes a recto-vaginal examination, palpation of the abdominal organs and all groups of peripheral lymph nodes, auscultation and percussion of the lungs, palpation of the mammary glands. The level of evidence for recommendations is A (the level of reliability of evidence is 1). Comment: special attention should be paid to assessing the patient's condition according to the WHO/ECOG and/or Karnofsky scale, assessing nutritional status, pain syndrome, body temperature, hemodynamics, enlarged peripheral lymph nodes, and the presence of pleurisy and ascites.

Laboratory diagnostic tests: it is recommended to perform a complete general (clinical) blood test, a general therapeutic biochemical blood test with assessment of liver and kidney function, a complete (clinical) urine test, and a study of the blood coagulation system for all patients with OC in order to assess the patient's condition, determine the patient's treatment tactics and algorithm, and assess the prognosis of the disease. The level of evidence for recommendations is C (the level of reliability of evidence is 4). Comments: A complete blood count is performed (repeated) at least 5 days before the start of the next course of chemotherapy; in a complete general (clinical) blood test, it is advisable to assess the following parameters: hemoglobin, hematocrit, erythrocytes, mean corpuscular volume, erythrocyte distribution by size, mean corpuscular hemoglobin content, mean corpuscular hemoglobin concentration, leukocyte platelets, leukocyte formula, erythrocyte sedimentation rate; in a general therapeutic biochemical blood test with an assessment of liver and kidney function indicators - total protein, glucose, bilirubin, creatinine, urea, iron, alanine aminotransferase, aspartate aminotransferase, total bilirubin, lactate aminotransferase, alkaline phosphatase, plasma electrolytes (potassium, sodium, chlorine), in a general (clinical) urine test - determination of color, transparency of urine, its specific gravity, protein in urine, pH, glucose, ketone bodies, urobilinogen, leukocyte esterase, by hardware microscopy of epithelial cells, erythrocytes, cylinders, salt, mucus, bacteria and fungi; as part of the study of the blood coagulation system, a coagulogram (an indicative study of the hemostasis system) is assessed (fibrinogen, prothrombin (according to Quick), international normalized ratio, prothrombin time, prothrombin index, activated partial thromboplastin time, thrombin time, if indicated, additionally - antithrombin III, D-dimer, plasminogen, % activity); it is recommended that all patients undergo a study of the level of adenogenic cancer antigen CA 125 in the blood in order to identify OC and its recurrence. The level of evidence for recommendations is A (the level of reliability of evidence is 1) [1].

In the absence of morphological verification of the diagnosis, it is recommended that all patients with suspected OC undergo determination of human epididymis protein 4 (HE4) in the blood and determination of the Risk of Ovarian Malignancy Algorithm (ROMA) index in order to

assess the probability of OC. The strength of the recommendations is B (the level of evidence is 2). Comment: determination of HE4 in the blood and the ROMA index does not replace the need for morphological verification of the diagnosis, but an elevated HE4 level increases the specificity of OC diagnostics; if mucinous carcinoma is suspected, it is recommended, in addition to testing the level of adenogenic cancer antigen CA 125 in the blood, to test the level of adenogenic cancer antigen CA 19-9 in the blood and test the level of carcinoembryonic antigen (CEA) in the blood serum for the purpose of differential diagnosis. The strength of the recommendations is A (the level of evidence is 2). Comment: CEA and CA19-9 may increase in mucinous OC, which allows for subsequent monitoring of the effectiveness of the treatment; for women under 40, who have a high probability of non-epithelial tumors, it is recommended to perform a study of the alpha-fetoprotein level in the blood serum, a study of the level of chorionic gonadotropin in the blood, and a study of the level of inhibin B in the blood at the diagnostic stage. The level of evidence for recommendations is C (the level of reliability of evidence is 5). Comment: non-epithelial ovarian tumors predominate at a young age (detailed information is provided in the section on non-epithelial ovarian tumors). All patients with high-grade serous and endometrioid carcinomas are recommended to undergo molecular genetic testing for mutations in the BRCA1 and BRCA2 genes in the blood or by scraping the oral mucosa and/or in biopsy (surgical) material as predictors of the disease outcome and the choice of the patient's treatment algorithm. The level of evidence for recommendations is B (the level of reliability of evidence is 2). Comment: the frequency of mutations in the BRCA1 and BRCA 2 genes in the indicated histological types of tumors is about 15%. Information about the presence of a BRCA mutation is useful for determining a higher sensitivity of the tumor to therapy with alkylating agents, platinum derivatives and poly (adenosine diphosphate-ribose) polymerase (PARP) inhibitors [1].

1. All patients with OC or suspected OC are recommended to undergo computed tomography (CT) of the chest, abdominal cavity, retroperitoneal space, and kidneys at the diagnostic stage, with or without intravenous contrast in order to determine the extent of the tumor process and plan the treatment algorithm. The level of evidence for recommendations is A (the level of reliability of evidence is 1). Comment: CT allows (a) to visualize the primary tumor, (b) to identify metastases of the disease, (c) to assess the possibility of performing an optimal cytoreductive surgery. If CT is contraindicated or insufficiently informative, magnetic resonance imaging (MRI) with intravenous contrast may be performed. If distant metastasis is suspected, positron emission tomography (PET)/CT may be performed.

2. All patients with OC or suspected OC are recommended to undergo MRI of the pelvic organs with or without intravenous contrast at the diagnostic stage in order to determine the extent of the tumor process and plan the treatment algorithm. The strength of the recommendations is A (the level of evidence is 1). Comment: MRI allows (a) to visualize the primary tumor, (b) to identify metastases of the disease, (c) to assess the possibility of performing an optimal cytoreductive surgery. In case of contraindications to MRI examination or its insufficiently informativeness, as well as when it is not possible to perform MRI, CT with or without intravenous contrast is indicated. If distant metastasis is suspected, PET/CT can be performed.

3. All patients with OC or suspected OC are recommended to undergo chest X-ray at the diagnostic stage if CT of the chest is not possible. The strength of the recommendations is C (the level of evidence is 5). Comment: CT of the chest organs is more sensitive and specific in detecting metastases in the lungs and mediastinal lymph nodes.

4. All patients with OC or suspected OC are recommended to undergo ultrasound examination of the lymph nodes in the cervical-supraclavicular region, axillary, inguinal lymph nodes, ultrasound of the abdominal cavity, retroperitoneal space and pelvis at the diagnostic stage if CT/MRI/PET-CT cannot be performed in order to determine the prevalence of the tumor process and plan the treatment algorithm. The level of evidence for recommendations is B (the level of

reliability of evidence is 2). Comment: Ultrasound is the simplest method for visualizing formations in the abdominal cavity, in the pelvic cavity, and secondary lymph node damage. However, this method is significantly inferior to CT/MRI/PET-CT in terms of making a decision on the first stage of treatment. Evaluation of the effect of chemotherapy according to RECIST 1.1 criteria is also impossible based on the results of ultrasound.

5. All patients with OC or suspected OC at the diagnostic stage are recommended to undergo examination of the mammary glands in order to exclude secondary (metastatic) ovarian lesions or primary multiple malignant neoplasms. The level of evidence for the recommendations is A (the level of reliability of the evidence is 1). Comments: Women under 40 years of age undergo ultrasound examination of the mammary glands in the first phase of the menstrual cycle, if available; women over 40 years of age are recommended to undergo mammography in the first phase of the menstrual cycle, if available. Examination of the mammary glands is carried out in accordance with the principles set out in the clinical guidelines for malignant neoplasms of the mammary glands.

6. For patients with OC, diagnostic laparoscopy is recommended to clarify the extent of the process, morphologically verify the diagnosis and assess resectability, as well as in cases where the performance of optimal cytoreduction is questionable for staging or if it was not adequately performed during previous cytoreduction, as well as for morphological verification of the diagnosis if less invasive methods are not effective [1].

As noted by Zhu B. et al. [2] the incidence and mortality of gynaecological cancers (GCs) can significantly impact women's quality of life and increase the health care burden for organisations globally. The objective of study was to evaluate global inequalities in the incidence and mortality of GCs in 2022, based on The Global Cancer Observatory (GLOBOCAN) 2022 estimates. The future burden of GCs in 2050 was also projected. Data regarding to the total cases and deaths related to GCs, as well as cases and deaths pertaining to different subtypes of GCs, gathered from the GLOBOCAN database for the year 2022. Predictions for the number of cases and deaths in the year 2050 were derived from global demographic projections, categorised by world region and Human Development Index (HDI). In 2022, there were 1 473 427 new cases of GCs and 680 372 deaths. The incidence of gynecological cancer reached 30.3 per 100 000, and the mortality rate hit 13.2 per 100 000. The age-standardised incidence of GCs in Eastern Africa is higher than 50 per 100 000, whereas the age-standardised incidence in Northern Africa is 17.1 per 100 000. The highest mortality rates were found in East Africa (age-standardised mortality rates of 35.3 per 100 000) and the lowest in Australia and New Zealand (age-standardised mortality rates of 8.1 per 100 000). These are related to the endemic areas of HIV and HPV. Very high HDI countries had the highest incidence of GCs, with age-standardised incidence rates of 34.8 per 100 000, and low HDI countries had the second highest incidence rate, with an age-standardised incidence rates of 33.0 per 100 000. Eswatini had the highest incidence and mortality (105.4 per 100 000; 71.1 per 100 000) and Yemen the lowest (5.8 per 100 000; 4.4 per 100 000). If the current trends in incidence and mortality are maintained, number of new cases and deaths from female reproductive tract tumours is projected to increase over the next two decades. In conclusion, the authors point out that in 2022, GCs accounted for 1 473 427 new cases and 680 372 deaths globally, with significant regional disparities in incidence and mortality rates. The highest rates were observed in Eastern Africa and countries with very high and low HDI, with Eswatini recording the most severe statistics. If current trends continue, the number of new cases and deaths from GCs is expected to rise over the next two decades, highlighting the urgent need for effective interventions.

OC is a leading cause of death in women worldwide, with more than 300,000 new cases and nearly 200,000 deaths globally each year [3].

Medina J.E. et al. emphasize in their work that [4], OC is a leading cause of death for women

worldwide, in part due to ineffective screening methods. Unfortunately, OC is usually detected in advanced stages (stages III and IV) due to nonspecific clinical symptoms at earlier stages and the lack of an effective screening approach. Consequently, there is a clear unmet clinical need for the development of highly specific and sensitive assays to detect OC in its earliest stages. In their study, the authors used whole-genome cell-free DNA (cfDNA) fragmentome and protein biomarker [cancer antigen 125 (CA-125) and HE4] analyses to evaluate 591 women with OC, with benign adnexal masses, or without ovarian lesions. Using a machine learning model with the combined features, researchers detected OC with specificity >99% and sensitivities of 72%, 69%, 87%, and 100% for stages I to IV, respectively. At the same specificity, CA-125 alone detected 34%, 62%, 63%, and 100%, and HE4 alone detected 28%, 27%, 67%, and 100% of OCs for stages I to IV, respectively. This approach differentiated benign masses from OCs with high accuracy (AUC = 0.88, 95% confidence interval, 0.83-0.92). These results were validated in an independent population. These findings show that integrated cfDNA fragmentome and protein analyses detect OCs with high performance, enabling a new accessible approach for noninvasive OC screening and diagnostic evaluation.

Qian F. et al. [5] in their study note that OC is the fifth leading cause of cancer deaths in US women, due to its typically advanced stage at presentation. Furthermore, unlike breast or colorectal cancer, there is no proven screening method for OC to identify early disease and initiate treatment to improve survival. Family history, oral contraceptive use, parity, body mass index (BMI), and genetic variants are potentially useful in estimating lifetime risk. Along with this, because of differences in age at onset and tumour histology/grade, risk factors for OC might be different for BRCA1/2 mutation carriers than women in the general population. Penetrance of BRCA1/2 mutations is likely modified by other genetic variants and lifestyle or reproductive factors. Investigation of these factors could aid in implementation of strategies to reduce OC risk among mutation carriers. In their work, the authors point out that height and BMI are associated with higher OC risk in the general population, but whether such associations exist among BRCA1/2 mutation carriers is unknown. The researchers applied a Mendelian randomisation approach to examine height/BMI with OC risk using the Consortium of Investigators for the Modifiers of BRCA1/2 data set, comprising 14,676 BRCA1 and 7912 BRCA2 mutation carriers, with 2923 OC cases. They created a height genetic score using 586 height-associated variants and a BMI genetic score using 93 BMI-associated variants. Associations were assessed using weighted Cox models. Observed height was not associated with OC risk (hazard ratio [HR]: 1.07 per 10-cm increase in height, 95% confidence interval [CI]: 0.94-1.23). Height genetic score showed similar results (HR=1.02, 95% CI: 0.85-1.23). Higher BMI was significantly associated with increased risk in premenopausal women with HR=1.25 (95% CI: 1.06-1.48) and HR=1.59 (95% CI: 1.08-2.33) per 5-kg/m² increase in observed and genetically determined BMI, respectively. No association was found for postmenopausal women. Interaction between menopausal status and BMI was significant (pinteraction<0.05). Our colleagues emphasize that the results of their observation of a positive association between BMI and OC risk in premenopausal BRCA1/2 mutation carriers is consistent with findings in the general population.

Jara-Rosales S. et al. [6] in their work they say that in 2020, OC ranked fourth in incidence among gynecological cancers worldwide, following breast cancer, cervical cancer, and uterine cancer. In terms of mortality, it ranked third, establishing itself as one of the most lethal gynecological cancers. A 2021 study revealed that the variability in the incidence depends on each country and region, but the mortality rate remains similar among the 185 countries included. This behavior is attributed to nonspecific symptoms and the lack of screening programs, leading to diagnoses at advanced stages with unfavorable prognoses for patients [7]. OC constitutes a group of diverse diseases, each characterized by its own morphology and biological behavior. This heterogeneity implies that different subtypes may respond differently to treatments and show

variations in their progression rates [8]. It is therefore essential to recognize this diversity to effectively address the different manifestations of OC. The risk factors for OC are divided into two categories: modifiable and non-modifiable. Modifiable factors include smoking, hormone replacement therapy, and dietary elements, among others. Non-modifiable factors include heredity, mutations in the BRCA1 and BRCA2 genes, family history, Lynch syndrome, uninterrupted ovulation cycles, and the presence of endometriosis, among others [7].

Our colleagues conducted an exhaustive search was conducted to identify literature to describe the OC biology and physiopathology for new readers, in particular focused on clinical researchers. In addition, a more stringent search was performed to find studies related to the genetic components, social determinants, and comorbidities associated with OC in South America. The search was performed through PubMed and Google Scholar, using the MeSH descriptors and keywords such as “Hereditary Breast and Ovarian Cancer Syndrome”, “Latin America”, “BRCA1 Genes”, “BRCA2 Genes”, and “Ovarian Neoplasms”. Additionally, the keywords “Obesity”, “chronic disease”, “Comorbidity”, “poverty”, “education”, “race”, “ethnicity”, “menarche”, “menopause”, “multiparity”, “urbanization”, “epidemiology”, and “risk factors” were utilized to capture relevant studies. Due the reported disparities in clinical trials and other biomedical studies, the Latin American population is greatly underrepresented in most of the cancer and genomic databases, including local investigations. For this reason, the number of identified reports according to the specific topics was very small for further analysis. The revision of the literature was conducted based on original articles, including cohort studies, case-control studies, cross-sectional studies, and experimental research investigating the risk factors for OC in the South American population, and the selected articles were published within the last 10 years, with full-text availability, and were written in English or Spanish. The authors considered studies involving women from 12 South American countries, without age restrictions, focusing particularly on those analyzing genetic components, socioeconomic determinants, and comorbidities. Considering the main goal of this work, they excluded studies focused on OC treatment, research validating laboratory tests for detecting OC-related mutations, and non-original content such as reviews, opinions, editorials, letters to the editor, and conference abstracts. Articles that did not clearly specify the region or country of interest, or those centered on education about OC risk factors, were also excluded. [6].

In the conclusions following from the study, the researchers note that based on the revised articles, it can be concluded that although there are reports on the prevalence of mutations in the BRCA1 and BRCA2 genes in South American countries, such as Chile, Colombia, Argentina, Uruguay, and Brazil, including Mexico as Hispanic, the general prevalence is close to 15-20% in women with hereditary risk factors or those diagnosed with ovarian and/or breast cancer. However, it is important to highlight that the available studies are limited. More research is needed to accurately determine the prevalence of the punctual mutation in each country, as well as those mutational signatures that could be unique for the Latin American population. In terms of the social, demographic, and economic factors that influence the incidence of OC, these vary by country, but similarities are observed in age, being more prevalent in women over 50 years old, and in women with poor education and difficulties in accessing healthcare. Similarly, the absence of studies regarding the effect of contraception and hormone replacement therapy in the Latin American population is highlighted, despite being widely studied factors in the international scientific literature. This gap in the research underscores the need to address these aspects in future research in the region. This article has several limitations, starting with the very limited number of studies published and the number of participants in each study. The revised literature covers several years of research conducted in each country; these years may represent disparities in funding for biomedical research, the number and capabilities of each research group and the possibility of enrolling patients, and the access to technological facilities. For now, it is not possible to conduct a more comprehensive analysis; however, this work may promote the interest of other

researchers to collaborate in the systematic revision of current and future data. Regarding the need to improve lifestyles as a preventive measure to reduce the possibility of morbidities and the concomitant development of OC, although the literature may not be sufficient to conclusively establish a direct link between obesity and/or diabetes and the development of OC, the indirect association suggests the importance of conducting additional clinical studies. These studies could confirm or dismiss the hypothesis that obesity and diabetes could be related to the risk of developing OC, thereby providing a more solid basis for future interventions and prevention strategies [6].

Bryant A. et al. [9] provide data showing that OC is the seventh most common cancer among women and a leading cause of death from gynaecological malignancies. Epithelial OC is the most common type, accounting for around 90% of all OCs. This specific type of OC starts in the surface layer covering the ovary or lining of the fallopian tube. Surgery is performed either before chemotherapy [upfront or primary debulking surgery (PDS)] or in the middle of a course of treatment with chemotherapy [neoadjuvant chemotherapy and interval debulking surgery (IDS)], with the aim of removing all visible tumour and achieving no macroscopic residual disease (NMRD). The aim of this study was to investigate the prognostic impact of size of residual disease (RD) nodules in women who received upfront or interval cytoreductive surgery for advanced (stage III and IV) epithelial OC (EOC). To assess the prognostic impact of RD after primary surgery on survival outcomes for advanced (stage III and IV) EOC. In separate analyses, primary surgery included both upfront PDS followed by adjuvant chemotherapy and neoadjuvant chemotherapy followed by IDS. Each RD threshold is considered as a separate prognostic factor. The authors searched CENTRAL (2021, Issue 8), MEDLINE via Ovid (to 30 August 2021) and Embase via Ovid (to 30 August 2021). Our colleagues included survival data from studies of at least 100 women with advanced EOC after primary surgery. RD was assessed as a prognostic factor in multivariate prognostic models. They excluded studies that reported fewer than 100 women, women with concurrent malignancies or studies that only reported unadjusted results. Women were included into two distinct groups: those who received PDS followed by platinum-based chemotherapy and those who received IDS, analysed separately. The researchers included studies that reported all RD thresholds after surgery, but the main thresholds of interest were microscopic RD (labelled NMRD), RD 0.1 cm to 1 cm [small-volume residual disease (SVRD)] and RD > 1 cm [large-volume residual disease (LVRD)]. Two review authors independently abstracted data and assessed risk of bias. Where possible, they synthesised the data in meta-analysis. To assess the adequacy of adjustment factors used in multivariate Cox models, authors used the 'adjustment for other prognostic factors' and 'statistical analysis and reporting' domains of the quality in prognosis studies tool.

Our colleagues also made judgements about the certainty of the evidence for each outcome in the main comparisons, using GRADE. The researchers examined differences between FIGO stages III and IV for different thresholds of RD after primary surgery. They considered factors such as age, grade, length of follow-up, type and experience of surgeon, and type of surgery in the interpretation of any heterogeneity. The authors also performed sensitivity analyses that distinguished between studies that included NMRD in RD categories of < 1 cm and those that did not. This was applicable to comparisons involving RD < 1 cm with the exception of RD < 1 cm versus NMRD. They evaluated women undergoing PDS and IDS in separate analyses. The researchers found 46 studies reporting multivariate prognostic analyses, including RD as a prognostic factor, which met inclusion criteria: 22,376 women who underwent PDS and 3697 who underwent IDS, all with varying levels of RD. While we identified a range of different RD thresholds, authors of the work mainly report on comparisons that are the focus of a key area of clinical uncertainty (involving NMRD, SVRD and LVRD). The comparison involving any visible disease (RD > 0 cm) and NMRD was also important. SVRD versus NMRD in a PDS setting In PDS studies, most showed an

increased risk of death in all RD groups when those with macroscopic RD (MRD) were compared to NMRD. Women who had SVRD after PDS had more than twice the risk of death compared to women with NMRD (HR 2.03, 95% CI 1.80 to 2.29; I² = 50%; 17 studies; 9404 participants; moderate-certainty). The analysis of progression-free survival found that women who had SVRD after PDS had nearly twice the risk of death compared to women with NMRD (HR 1.88, 95% CI 1.63 to 2.16; I² = 63%; 10 studies; 6596 participants; moderate-certainty). LVRD versus SVRD in a PDS setting. When authors compared LVRD versus SVRD following surgery, the estimates were attenuated compared to NMRD comparisons. All analyses showed an overall survival benefit in women who had RD < 1 cm after surgery (HR 1.22, 95% CI 1.13 to 1.32; I² = 0%; 5 studies; 6000 participants; moderate-certainty). The results were robust to analyses of progression-free survival. SVRD and LVRD versus NMRD in an IDS setting The one study that defined the categories as NMRD, SVRD and LVRD showed that women who had SVRD and LVRD after IDS had more than twice the risk of death compared to women who had NMRD (HR 2.09, 95% CI 1.20 to 3.66; 310 participants; I² = 56%, and HR 2.23, 95% CI 1.49 to 3.34; 343 participants; I² = 35%; very low-certainty, for SVRD versus NMRD and LVRD versus NMRD, respectively). LVRD versus SVRD + NMRD in an IDS setting meta-analysis found that women who had LVRD had a greater risk of death and disease progression compared to women who had either SVRD or NMRD (HR 1.60, 95% CI 1.21 to 2.11; 6 studies; 1572 participants; I² = 58% for overall survival and HR 1.76, 95% CI 1.23 to 2.52; 1145 participants; I² = 60% for progression-free survival; very low-certainty). However, this result is biased as in all but one study it was not possible to distinguish NMRD within the < 1 cm thresholds. Only one study separated NMRD from SVRD; all others included NMRD in the SVRD group, which may create bias when comparing with LVRD, making interpretation challenging. MRD versus NMRD in an IDS setting. Women who had any amount of MRD after IDS had more than twice the risk of death compared to women with NMRD (HR 2.11, 95% CI 1.35 to 3.29, I² = 81%; 906 participants; very low-certainty). Summing up the results of the study, the authors point out that in a PDS setting, there is moderate-certainty evidence that the amount of RD after primary surgery is a prognostic factor for overall and progression-free survival in women with advanced OC. Our colleagues separated our analysis into three distinct categories for the survival outcome including NMRD, SVRD and LVRD. After IDS, there may be only two categories required, although this is based on very low-certainty evidence, as all but one study included NMRD in the SVRD category. The one study that separated NMRD from SVRD showed no improved survival outcome in the SVRD category, compared to LVRD. Further low-certainty evidence also supported restricting to two categories, where women who had any amount of MRD after IDS had a significantly greater risk of death compared to women with NMRD. Therefore, the evidence presented in this review cannot conclude that using three categories applies in an IDS setting (very low-certainty evidence), as was supported for PDS (which has convincing moderate-certainty evidence) [9].

What knowledge is available today about the specifics of OC treatment? Drug resistance is the bottleneck in OC treatment. The increasing use of novel drugs in clinical practice poses challenges for the treatment of drug-resistant OC. Although maintenance therapy with PARP inhibitors (PARPis) has prolonged progression-free survival and 5-year overall survival, unfortunately, many patients do not respond to PARPis treatment due to intrinsic or acquired resistance [10].

Wang L. et al. [11] indicate that despite receiving standard-of-care therapy (optimal cytoreductive surgery followed by adjuvant chemotherapy), most patients develop recurrent disease, which is resistant to chemotherapy, resulting in a 5-year survival rate of approximately 30-40% worldwide. Drug resistance is a formidable challenge in the treatment of OC and is the primary contributor to poor prognosis. According to the National Comprehensive Cancer Network guidelines (version 1.2023), there are many therapeutic regimens for resistant OC, including some novel agents. However, the objective remission rate is still low, and the median survival time is

less than 12 months due to complicated resistance mechanisms. In resistant OC, the classical mechanisms of action of common drugs can be disrupted or altered, possibly resulting in impaired therapeutic effects. Thus, treatment regimens should not rely only on empirical options. As the number of categories of agents increases, after the development of multidrug resistance, the decision of appropriate later-line therapeutic regimens is very challenging. The authors reviewed the literature regarding various drug resistance mechanisms in OC and found that the main resistance mechanisms are as follows: abnormalities in transmembrane transport, alterations in DNA damage repair, dysregulation of cancer-associated signaling pathways, and epigenetic modifications. DNA methylation, histone modifications and noncoding RNA activity, three key classes of epigenetic modifications, constitute pivotal mechanisms of drug resistance. One drug can have multiple resistance mechanisms. Moreover, common chemotherapies and targeted drugs may have cross (overlapping) resistance mechanisms. MicroRNAs (miRNAs) can interfere with and thus regulate the abovementioned pathways. A subclass of miRNAs, “epi-miRNAs”, can modulate epigenetic regulators to impact therapeutic responses. Thus, they also reviewed the regulatory influence of miRNAs on resistance mechanisms. Moreover, researchers summarized recent phase I/II clinical trials of novel drugs for OC based on the abovementioned resistance mechanisms. A multitude of new therapies are under evaluation, and the preliminary results are encouraging. Summarizing the results of the study, our colleagues emphasize that with the increasing use of novel therapeutic drugs for OC, the development of later-line treatments has been under enormous pressure. Recently, resistance to a variety of therapeutic drugs, such as PARPis, angiogenesis inhibitors, and immune checkpoint inhibitors, has been found to occur. In the past, therapeutic agents for OC have been limited, and researchers have usually described the underlying mechanism and explored therapeutic strategies for overcoming resistance based on the drug classification. However, as increasing numbers of new agents are applied in clinical practice, the resistance mechanisms of these various new drugs must be identified, and these mechanisms may be similar or even identical to those of other drugs. Thus, the classification of drug resistance should not be confined to the drug category, and all should attempt to obtain insight into classification of resistance based on molecular mechanisms. The concept of drug resistance classification provides a sound basis for further research to develop more precise reversal strategies.

Instead of simply distinguishing resistance by agent, researchers attempted to classify drug resistance by mechanism. The authors summarized four major mechanisms from the published literature: 1) abnormalities in transmembrane transport, 2) alterations in DNA damage repair, 3) dysregulation of cancer-associated signaling pathways, and 4) epigenetic modifications. In the context of the increasing number of novel agents, summary of the four resistance mechanisms of OC provides a new concept for resistance classification by molecular mechanism, not by drug category. Given the intersections between drug resistance mechanisms, this concept is likely to result in the realization of “two birds with one stone” effects on the reversal of drug resistance in OC. Furthermore, these findings are anticipated to have broad implications for the development of precise therapeutic approaches for reversing drug resistance in OC. On this basis, umbrella trials can be carried out to explore the diagnostic and therapeutic targets of the four resistance mechanisms, and this may be a direction of future researches on drug resistance in OC [11].

As Porter J.M. et al. [12] note in their study epithelial OC (ovarian carcinoma) is the most common form of the disease and comprises multiple histological types (histotypes): high-grade serous (70% of patients), endometrioid (10%), clear cell (10%), low-grade serous ($\leq 5\%$), and mucinous ($\leq 5\%$). Ovarian carcinosarcomas - previously considered a separate disease entity - are now recognized to represent metaplastic carcinomas and account for no more than 5% of diagnoses. A wealth of evidence now demonstrates that each histotype represents a unique disease entity, each with distinct developmental origins, molecular landscapes, intrinsic

chemosensitivity, survival profile, and susceptibility to targeted molecular therapeutics.

The authors emphasize that complete macroscopic resection is a key factor associated with prolonged survival in OC. That being said, patients with clear cell ovarian carcinoma and low-grade serous ovarian carcinoma represent some of the groups that benefit most from achieving complete macroscopic resection; given that these cases are unlikely to respond well to neoadjuvant chemotherapy, complete primary cytoreduction is a major priority for these patients. Endometrioid ovarian carcinoma also represents a histotype in which complete macroscopic resection is associated with marked patient survival benefit. Engagement with multiple surgical teams to improve the likelihood of resecting disease at hepatobiliary, gastrointestinal, and other anatomical sites beyond the pelvis will be key for delivering optimal outcomes for such cases that present with extensive advanced-stage disease. More work is also required to understand the impact of resecting disease outside of the pelvis and abdomen. Achievement of complete macroscopic resection across the overall OC patient population is associated with markedly prolonged survival time, though differences in the degree of survival benefit are apparent across different histotypes. Patients with clear cell ovarian carcinoma derive one of the greatest survival benefits associated with complete macroscopic resection. High-grade serous ovarian carcinoma patients demonstrate highly clinically and statistically meaningful survival benefit, but the magnitude of benefit is lower than in some of the other histotypes. The extent of benefit from complete macroscopic resection does not appear to relate solely to levels of intrinsic chemosensitivity of each histotype [12].

Now, as for this pathology in our country at the republican level. The incidence of OC in the Republic of Kazakhstan in 2023 was 6.3 per 100 thousand population (6.2 in 2022) with a growth rate of 2.1% compared to the previous year, amounting to 1,251 people in absolute numbers (1,201 women a year earlier). The proportion of cases with a diagnosis established for the first time in life, recorded by oncological organizations, was 3.4%, as in the previous year in the general population, and 6.0% among women (in 2022 also 6.0%) and 4th rank place after breast cancer, cervical cancer and endometrial cancer [13].

Above the national average, OC was established in 8 regions of the country: the city of Almaty - 10.4 (maximum indicator); Pavlodar - 9.7; Karaganda - 8.6; Abay - 8.4; Akmola - 7.7; Kostanay - 7.6; North Kazakhstan - 7.5; West Kazakhstan - 7.2. Aktobe, Atyrau and Kyzylorda regions are on par with the national average. This indicator is lower than the national average in the remaining 9 regions: Turkestan - 2.9 (the lowest level); Mangistau - 3.5; Ulytau - 3.6; Almaty - 3.7; Zhambyl - 4.3; the city of Shymkent - 4.6; East Kazakhstan - 5.8; Zhetysu - 5.9 regions and the city of Astana - 6.2 per 100 thousand people. The mortality rate from this pathology in 2023 was 2.1, a year earlier - 2.4 per 100 thousand population. The regions where the mortality rate from OC is higher than the average in the republic (2.1 per 100 thousand population) include: Abay - 3.0 (maximum level); the city of Astana - 2.9; Karaganda and Pavlodar - 2.5; Kyzylorda - 2.4; Aktobe and the city of Almaty - 2.2. This indicator is at the same level with the national average in the East Kazakhstan region. The lowest rates were noted in Turkestan - 1.5 (minimum rate); Almaty and Atyrau - 1.6; Zhambyl - 1.7; Ulytau and Mangistau - 1.8; North Kazakhstan and Kostanay - 1.9; West Kazakhstan, Zhetysu, Akmola regions and the city of Shymkent - 2.0 per 100 thousand population [13].

The one-year lethality rate was 14,7% (16,2% in 2022). At the same time, the ratio between one-year lethality and neglect (stage IV) was quite high - 1.9 (a year earlier it was even higher - 2.1. At the same time, it should be noted that the farthest from "1" is the worst ratio between one-year lethality and neglect.

Now, regarding preventive examinations. It should be noted that during large-scale preventive examinations of the population in 2023, significantly more patients with malignant neoplasms were actively identified than in 2022. This is 25,193 patients against 23,623 patients

identified in 2022, i.e. +6.6%. This is due to the further abatement of the epidemiological troubles due to coronavirus and the increased availability of preventive care for the population. The proportion of patients identified during preventive examinations increased from 62.0% to 62.4% of the total number of patients identified per year.

Of course, with in the analysis of the epidemiological situation, the indicators of early diagnostics are very important issues. In general, in terms of the amount of detected cases of cancer of all localizations, in 2023 the proportion of forms detected at early stages (0, I-II stages) increased from 66.3% to 67.9%. As for OC, the early detection of this pathology during preventive examinations increased from 40.5 to 44.8%. The number of newly diagnosed patients with OC registered with oncology organizations amounted to 1,218 people (1,173 - a year earlier). At the same time, the absolute number of cases detected during preventive examinations in 2023 was 863, in 2022 - 875; the proportion of cases detected during preventive examinations was 70.9% and 74.6%, respectively. Of these, patients with stages I-II - 387 in 2023 and 354 in 2022.

The regions where the proportion of patients with early stage I of the pathology in question is above the national average (31.0% and 9th place among all nosological forms of malignant neoplasms) include the following regions: the city of Almaty - 45.3%; (the best indicator); Zhetysu - 43.9%; the city of Astana - 42.2%; Zhambyl - 38.5%; Kyzylorda - 35.8%; East Kazakhstan and Akmola - 35.0%; Kostanay - 33.9%; Almaty - 33.3%.

The lowest rates of early diagnosis were recorded in 11 regions. Against this background, two regions stand out - Aktope and Turkestan, where stage I of the disease was established at only 5.2% and 6.5%, respectively (the worst rates in the republic). Next come: Mangistau - 16.0%; the city of Shymkent - 18.5%; Pavlodar - 23.3%; Abay - 23.4%; Ulytau and West Kazakhstan - 25.0%; Karaganda - 25.5%; Atyrau - 28.6% and North Kazakhstan - 30.8% of the region [13]. It should be noted that only two patients out of every five were detected in the early (I-II stages) of this pathology, making up 41.7% in the republic. The regions where the proportion of patients with OC detected at stages I-II is higher than the national average include the following regions. The best indicator is in the Zhetysu region - 51.2%. Then come two megacities - the cities of Almaty (51.6%) and Astana (50.6%); then - East Kazakhstan and Atyrau (50.0%); Akmola (48.3%); Mangistau (48.0%); Kostanay (45.2%); Zhambyl (44.2%); North Kazakhstan (43.6%); Karaganda (42.6%) regions. Low rates of early diagnosis were recorded in the following regions. Against the general background, the Aktope region stands out negatively, where only every tenth patient was detected in the early stages of the disease - 10.3%. Then come the following regions: Turkestan (16.1%); Shymkent city (31.5%); West Kazakhstan (33.3%); Abay (34.0%); Almaty (37.0%); Ulytau (37.5%); Pavlodar (41.1%) and Kyzylorda (41.5%) regions [13].

As can be clearly seen from the above data, there is a very large spread in early diagnostic rates across the country, from good to disappointing. Of course, it is necessary to take into account migration processes and other factors that affect early diagnostic rates, but nevertheless, the results obtained give reason not to stop there, both for oncologists and gynecological oncologists, as well as for obstetricians and gynecologists, visual diagnostic doctors, and general practitioners, since improving the rates of early diagnostics of malignant tumors has remained one of the main postulates and one of the main tasks of medicine in general, and continues to be relevant today. The proportion of stage IV OC among all nosological forms of malignant neoplasms was 7.2%, and this is the 17th rank. In general, in 2023, the proportion of malignant neoplasms of stage IV in the republic for the sum of all nosologies decreased from 12.58 to 11.7% (from 4790 to 4735 patients).

As for the average national indicator of the proportion of stage IV (7.2%), Zhetysu and Mangistau regions stand out against this background - 0.0%. Then come: Kyzylorda and Zhambyl (1.9%); Atyrau (2.4%); North Kazakhstan (2.6%); the city of Almaty (3.6%); East Kazakhstan (5.0%); Pavlodar (5.5%). The city of Astana is on the same level with the average national indicator. The indicators are lower in the following regions. Abay region stands apart from all others, where every

fifth patient is diagnosed in the terminal stage of the disease (21.3%). Next come: Turkestan (12.9%); Karaganda (12.8%); Ulytau (12.5%); Aktobe (12.1%); the city of Shymkent (11.1%); Akmola (10.0%); Kostanay (9.7%); West Kazakhstan (8.3%); Almaty (7.4%) regions.

The morphological verification rate of the disease in the country was 84.3%. In 5 regions out of 20, this is a 100% figure (East Kazakhstan, Zhambyl, Ulytau regions, as well as the cities of Astana and Shymkent). The lowest figure is in the Kyzylorda region (32.1%). Next on this list are the city of Almaty (55.2%); Zhetysay (78.0%); Mangistau and Akmola (80.0%); Aktobe (91.4%); Atyrau (92.9%); West Kazakhstan (93.8%); North Kazakhstan (94.9%); Turkestan and Kostanay (95.2%); Karaganda (95.7%); Pavlodar (95.9%); Almaty (96.3%) and Abay (97.9%) regions [13].

The total number of patients with malignant neoplasms, consisting of registered in specialized oncological organizations of the republic, continued to grow and by the end of 2023 amounted to 218,186 people, with an increase of 6.0% compared to the level of the previous year (2022 - 205,822, +5.8%). The overall incidence rate of malignant neoplasms increased by 3.9%, from 1055.3 to 1096.4 per 100 thousand population. The growth of this indicator is due to both the increase in the incidence and detection of pathology, and the increase in the survival rate of cancer patients. In addition, statistical data on patients diagnosed with malignant neoplasms, who have been under observation for 5 years or more, and continue to be observed in 2023, showed that the number of patients under observation by oncological organizations in Kazakhstan for over five years continued to grow and at the end of the reporting year amounted to 117,616 people, with an increase of 6.2% (2022 - 110,790 people, +6.6%) (form. No. 7).

It is impossible to ignore such an important clinical aspect as the coverage of patients with a first-ever diagnosis of OC in the Republic of Kazakhstan with specialized treatment.

In 2023, the number of hospitalizations for all nosological forms of malignant tumors in the country's oncology organizations amounted to 108,252 cases (2022 - 101,095), with an increase of 7.1% compared to the previous year, which is associated with a constant increase in the number of cancer patients, improved standardization of oncological care, and the development of palliative and restorative services.

At the end of 2023, the absolute number of patients with OC who completed specialized treatment amounted to 697 people, continuing treatment - 387 patients. The following results were obtained in percentage terms by methods and types of treatment. The overwhelming majority of patients received complex treatment - 68.4%, only surgical treatment - 21.1%, only drug treatment - 8.3%; combined - 0.3%, chemo-radiation - 0.1%.

Next, regarding the five-year survival rate of patients. As for OC, at the end of 2023, 8229 people or 41.4 per 100 thousand of the population were registered with the dispensary (at the end of 2022 - 7864 patients or 40.3 per 100 thousand of the population, respectively); and this is the 9th rank place among all nosological forms of malignant neoplasms.

At the same time, the mortality rate of the observed contingents in 2023 was 5.0% (6.0% - in 2022).

The five-year survival rate of patients with OC was 58.2% in 2023 (57.5% - a year earlier) [13].

Summarizing the above, we can conclude that OC occupies a significant place among all existing malignant tumors of other localizations. At the same time, despite the small percentage of patients detected at stage IV, taking into account a number of factors, the indicators of early diagnostics do not allow oncologists to "sleep peacefully", since the locally advanced stage III, which significantly prevails over all stages, in addition to the prevalence itself, gives a large number of complications and locoregional metastases, and these patients are subject to aggressive complex treatment, constituting the overwhelming percentage (68.4%) among all methods of treating this pathology. The variability and veiling of symptoms, its similarity with various non-core processes (sometimes the only symptom is a gradual increase in the abdomen due to ascites),

leads to the neglect of the disease. All this requires both oncologists and gynecological oncologists, and, first of all, primary health care workers, as well as obstetricians and gynecologists and visual diagnostics doctors, to increase the level of cancer alertness, inform the population about early symptoms that may indicate this pathology or the onset of proliferative changes and conduct high-tech diagnostic measures and, as a result, timely treatment. Women at risk are advised to visit specialized specialists annually and, if necessary, undergo an examination.

An epidemiological assessment of the situation with OC in our country suggests that there are sometimes significant differences between regions not only in incidence rates, but also in the parameters of early diagnosis and mortality from this pathology. In connection with the above, this pathology continues to be a serious problem in modern clinical oncology.

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Psychological Sciences

Влияние стресса на соматические и психические функции организма: расширенный анализ

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В данной статье рассматривается стресс как универсальный биологический феномен, представляющий собой любой внутренний или внешний стимул, вызывающий физиологическую реакцию организма. Подчеркивается, что ответные реакции организма (стресс-ответы) направлены на компенсацию нарушений и поддержание гомеостаза.

Авторы отмечают, что влияние стресса определяется его характеристиками — типом, продолжительностью и интенсивностью. В зависимости от этих факторов стресс может вызывать широкий спектр последствий: от незначительных изменений в регуляции гомеостаз до тяжёлых патологических состояний и летального исхода.

Особое внимание уделяется роли стресса в развитии заболеваний. Подчеркивается, что стресс способствует возникновению патофизиологических нарушений, увеличивает риск развития различных заболеваний у людей, находящихся в хронически стрессовых условиях, может выступать как пусковым механизмом, так и фактором, усугубляющим течение болезней. В работе также представлен обзор влияния стресса на основные физиологические системы организма человека, что позволяет рассматривать стресс как важный междисциплинарный фактор, затрагивающий как соматическое, так и психическое здоровье [1].

Данное исследование посвящено изучению уровня стресса и стратегий совладания с ним среди студентов-медсестёр в условиях ограниченных ресурсов (на примере Малави). Подчеркивается, что обучение в сестринских программах сопровождается значительной психоэмоциональной нагрузкой, однако данный контекст ранее был недостаточно изучен.

Исследование имело количественный поперечный дизайн и показало, что большинство студентов испытывают умеренный уровень стресса, при этом наибольший вклад вносит академическая нагрузка по сравнению с клиническими и внешними факторами. Основными источниками стресса выступают преподаватели, клинические наставники и медицинский персонал. Более высокий уровень стресса выявлен у студентов второго курса и у обучающихся на самофинансировании.

Авторы делают вывод о необходимости разработки интервенций по снижению стресса, а также подчеркивают важность дальнейших исследований, особенно в отношении риска формирования зависимого поведения [2].

В исследовании рассматривается влияние стресса на процессы памяти, с акцентом на нейронные механизмы кодирования эмоционально значимой информации. В отличие от предыдущих работ, сосредоточенных на реакции мозга на стимул, авторы изучают влияние стресса на предшествующую стимулу нейронную активность.

Эксперимент с участием 69 человек показал, что стресс изменяет нейронный контекст формирования памяти. В контрольной группе успешное запоминание было связано с тета-активностью до предъявления стимула, тогда как у участников в состоянии стресса ключевую роль играла гамма-активность, особенно при обработке эмоционального материала.

Кроме того, стресс влияет на межчастотные взаимодействия мозговых ритмов (в частности, тета-бета и тета-гамма связи), определяющие эффективность последующего запоминания. Эти изменения зависят от эмоциональной значимости информации.

Авторы приходят к выводу, что стресс не просто влияет на обработку информации, но и перестраивает нейронные условия, в которых формируется память, усиливая при этом кодирование эмоционально значимых событий [3].

Исследование было посвящено анализу взаимосвязи между уровнем воспринимаемого стресса и изменениями в работе желудочно-кишечного тракта у студентов в разные периоды учебного процесса.

В ходе сравнительного анализа было установлено, что в период экзаменов уровень стресса у студентов значительно выше по сравнению с менее напряжёнными учебными периодами. При этом более 40% участников сообщили о функциональных изменениях со стороны пищеварительной системы.

Выявлена статистически значимая связь между уровнем стресса и нарушениями желудочно-кишечных функций, что подтверждает влияние психоэмоционального напряжения на соматическое состояние. Подобные проявления можно рассматривать в рамках психосоматика как типичный пример телесной реакции на стресс.

Авторы приходят к выводу, что стрессовые события у молодых людей сопровождаются не только психологическими, но и физиологическими изменениями, в частности развитием функциональных гастроинтестинальных симптомов [4].

Статья посвящена стрессовым реакциям бактерий рода *Rhodococcus*, которые обладают высокой устойчивостью к неблагоприятным условиям благодаря особенностям клеточной стенки и широкому спектру ферментов, разрушающих или детоксифицирующих вредные соединения. Эти свойства делают их ценными для биотрансформаций, биodeградации и биоремедиации, однако сами биотехнологические процессы создают стрессовые условия, влияющие на эффективность бактерий.

Рассматриваются адаптации клеточной оболочки, формирование многоклеточных структур, стрессовые реакции при взаимодействии с хозяевами, а также роль сигма-факторов РНК-полимеразы в глобальной регуляции стресс-ответов.

Авторы подчеркивают, что обзор не является исчерпывающим, а служит для демонстрации взаимосвязи стрессовых реакций с биотехнологическими применениями и выявления пробелов в современных знаниях, стимулируя дальнейшие исследования [5].

В статье рассматривается феномен фенотоза — регулируемой формы гибели организма под воздействием стрессов, как на клеточном, так и на организменном уровне. Авторы отмечают, что в отличие от хорошо изученной апоптозной гибели клеток, механизмы фенотоза и его эволюционное значение остаются малоизученными.

Обзор включает данные о стресс-индуцированной фенотозной гибели на примере многоклеточного организма *C. elegans** и стрессовых реакций в клетках от бактерий до млекопитающих, акцентируя внимание на абиотических и патогенных стрессах. Выявлено, что гены и сигнальные пути, участвующие в фенотозе, способствуют гибели организма при сильном стрессе и старении, но при умеренных стрессах и в ранней жизни повышают

приспособленность и иммунную защиту — что соответствует концепции антагонистической плейотропии.

Авторы предполагают, что фенотоз может приносить популяционные и эволюционные преимущества, включая механизм родственного отбора (kin selection), защиту от инфекций (abortive infection), перераспределение ресурсов от соматических клеток к гаметам (soma-to-germline resource allocation).

Обзор предлагает концептуальные модели и экспериментально проверяемые гипотезы, способствующие пониманию роли стресс-индуцированного фенотоза и его связи с естественным старением [6].

Основная часть

Стресс представляет собой универсальную неспецифическую реакцию организма на воздействие различных стрессоров (физических, психологических, социальных), направленную на поддержание гомеостаза и адаптацию к изменяющимся условиям среды. Данный феномен занимает центральное место в исследованиях психологии, нейрофизиологии и психосоматики. Несмотря на адаптивную функцию, длительное воздействие стресса приводит к нарушению регуляторных систем организма и формированию патологических состояний.

Теоретические основы и стадии стрессовой реакции

Классическая концепция стресса была предложена Ганс Селье, который рассматривал стресс как общий адаптационный синдром. Согласно данной модели, выделяются три стадии:

1. Стадия тревоги — первичная мобилизация ресурсов организма в ответ на стрессор.
2. Стадия резистентности — адаптация и относительная стабилизация физиологических показателей при продолжающемся воздействии.
3. Стадия истощения — снижение адаптационных возможностей и развитие нарушений.

Длительное пребывание на стадии резистентности с последующим переходом к истощению лежит в основе негативного влияния хронического стресса.

Нейроэндокринные механизмы стресса

Ключевую роль в реализации стрессовой реакции играет гипоталамо-гипофизарно-надпочечниковая ось (ГГН-ось). Активация данной системы включает секрецию кортикотропин-рилизинг-гормона гипоталамусом, выделение адренотропного гормона гипофизом, продукцию глюкокортикоидов (прежде всего кортизола) корой надпочечников.

Кортизол обеспечивает мобилизацию энергетических ресурсов, усиливает глюконеогенез и оказывает иммуномодулирующее действие.

Параллельно активируется симпатико-адреналовая система, что сопровождается выбросом катехоламинов. Эти процессы реализуют реакцию «бей или беги», обеспечивая кратковременную адаптацию.

Однако при хроническом стрессе наблюдается дисрегуляция ГГН-оси, что приводит к нарушению циркадных ритмов секреции кортизола и истощению регуляторных механизмов.

Как известно стресс влияет на соматические системы:

1. Сердечно-сосудистая система

Хронический стресс способствует устойчивому повышению артериального давления, увеличению сосудистого тонуса и ускорению атерогенеза. Это повышает риск ишемической болезни сердца и инсульта.

2. Иммунная система

Длительное воздействие глюкокортикоидов приводит к иммунодепрессии. Снижается активность лимфоцитов и нарушается продукция цитокинов, что делает организм более уязвимым к инфекциям и замедляет процессы восстановления.

3. Пищеварительная система

Стресс влияет на моторику и секрецию желудочно-кишечного тракта, что может приводить к гастритам, язвенной болезни и синдрому раздражённого кишечника.

4. Опорно-двигательная система

Повышенный мышечный тонус вызывает хроническое напряжение, особенно в области шеи и спины, что сопровождается болевыми синдромами.

5. Эндокринные и метаболические эффекты

Нарушения в работе эндокринной системы могут приводить к инсулинорезистентности, увеличению массы тела и другим метаболическим расстройствам.

Влияние стресса на центральную нервную систему и психику

Современные исследования показывают, что стресс влияет на нейропластичность — способность мозга изменять свою структуру и функции.

Хронический стресс оказывает выраженное влияние на такие структуры головного мозга как гиппокамп, префронтальная кора и амигдала. Под воздействием хронического стресса уменьшается объём гиппокампа, снижается плотность нейронных связей в префронтальной коре и усиливаются связи в амигдале, отвечающей за страх

Гиппокамп страдает от нейротоксического действия кортизола, что приводит к ухудшению памяти. Снижается способность к планированию и контролю поведения и усиливается реакция страха и тревоги. Это приводит к тому, что человек становится более чувствительным к негативным стимулам и хуже справляется с регуляцией эмоций.

Стресс влияет не только на физиологию, но и на способы обработки информации. В условиях хронического напряжения усиливаются так называемые когнитивные искажения: катастрофизация (ожидание худшего исхода), чёрно-белое мышление, гиперобобщение негативного опыта. В когнитивной сфере это проявляется снижением концентрации внимания, ухудшением рабочей памяти и нарушением процессов принятия решений. Это поддерживает тревожные состояния и затрудняет объективную оценку ситуации. В эмоциональной сфере наблюдаются повышение уровня тревожности, раздражительность, эмоциональная нестабильность и склонность к аффективным реакциям.

Аллостатическая нагрузка как ключевой механизм

В современной науке всё чаще используется понятие аллостатическая нагрузка. Оно описывает «цену адаптации», которую организм платит за постоянное приспособление к стрессовым условиям. При хроническом стрессе системы регуляции (нервная, эндокринная, иммунная) работают в перегруженном режиме, что приводит к накоплению физиологических повреждений, ускоренному старению организма и снижению адаптационных резервов

Хронический стресс является фактором риска развития психических расстройств, включая депрессивное расстройство, тревожные расстройства и синдром эмоционального выгорания. Хронический стресс существенно влияет на поведенческие стратегии. Нередко формируются дезадаптивные способы совладания. Например, переедание или потеря аппетита, злоупотребление алкоголем или другими веществами, прокрастинация.

Психосоматические взаимодействия

В рамках психосоматики стресс рассматривается как ключевой фактор, связывающий психические процессы и соматические заболевания. Психоэмоциональное напряжение может способствовать возникновению и обострению заболеваний через нейроэндокринные и иммунные механизмы.

Формируется так называемый «порочный круг»: соматические симптомы усиливают психологический стресс, который, в свою очередь, усугубляет физическое состояние.

Индивидуальная реакция на стресс зависит от ряда факторов: личностных особенностей, уровня психологической устойчивости, социального окружения и наличия стратегий совладания (копинг-стратегий). Реакция на стресс варьируется в зависимости от генетических факторов, раннего жизненного опыта, уровня социальной поддержки и личностных характеристик. Например, высокий уровень резильентности позволяет эффективнее адаптироваться к стрессовым условиям без выраженных негативных последствий.

Эффективные методы регуляции стресса включают когнитивно-поведенческие техники, физическую активность, нормализацию сна и развитие навыков эмоциональной регуляции. Когнитивно-поведенческий подход позволяет выявлять и корректировать когнитивные искажения, снижая уровень тревожности. Практики осознанности способствуют снижению активности амигдалы и нормализации работы ГГН-оси. Регулярные нагрузки уменьшают уровень кортизола и повышают выработку эндорфинов. Межличностные связи играют важную роль в снижении стрессовой реакции.

Заключение

Стресс является комплексным биопсихосоциальным феноменом, затрагивающим все уровни функционирования организма. Его кратковременные проявления носят адаптивный характер, тогда как хронический стресс приводит к системной дезадаптации, нарушению работы физиологических систем и развитию психических расстройств.

Современные исследования подчеркивают необходимость комплексного подхода к изучению и управлению стрессом, включающего как биологические, так и психологические методы воздействия.

Современная наука активно изучает влияние стресса на экспрессию генов (эпигенетика), связь стресса с воспалительными процессами и роль микробиоты кишечника в регуляции стрессовой реакции. Эти направления открывают новые возможности для профилактики и терапии стресс-ассоциированных состояний.

Таким образом, стресс представляет собой многоуровневый процесс, затрагивающий нейроэндокринные, когнитивные и поведенческие механизмы. Его хроническое воздействие приводит к накоплению аллостатической нагрузки, нарушению нейропластичности и формированию устойчивых психосоматических расстройств.

Понимание этих процессов позволяет разрабатывать эффективные стратегии профилактики и коррекции, направленные на поддержание как психического, так и физического здоровья.

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Взаимосвязь движения, эмоций и сознания в танцевальной импровизации: теоретический анализ

The Interrelationship of Movement, Emotions, and Consciousness in Dance Improvisation: A Theoretical Analysis

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Аннотация

В статье представлен теоретический анализ взаимосвязи движения, эмоций и сознания в танцевальной импровизации в контексте развития эмоционального интеллекта. Актуальность исследования обусловлена возрастающим интересом к телесно-ориентированным практикам и их роли в формировании эмоциональной осознанности, а также недостаточной разработанностью проблемы импровизации как психофизического процесса. Целью работы является выявление закономерностей взаимодействия двигательных, эмоциональных и когнитивных компонентов в условиях спонтанного движения. В рамках исследования проанализированы современные теоретические подходы к пониманию эмоционального интеллекта, телесности и импровизации, а также рассмотрены концепции, раскрывающие роль движения как формы мышления и саморегуляции. Показано, что танцевальная импровизация представляет собой целостный процесс, в котором движение, эмоции и сознание находятся в постоянном взаимовлиянии, образуя единую динамическую систему. Обоснована роль эмоционального интеллекта как ключевого механизма, обеспечивающего осознание, дифференциацию и регуляцию внутреннего опыта в процессе движения. Делается вывод о том, что танцевальная импровизация может рассматриваться как эффективная психологическая практика, способствующая развитию эмоциональной чувствительности, саморегуляции и эмпатии.

Annotation

This article presents a theoretical analysis of the interrelationship between movement, emotions, and consciousness in dance improvisation in the context of emotional intelligence development. The relevance of the study is determined by the growing interest in body-oriented practices and their role in fostering emotional awareness, as well as the insufficiently explored nature of improvisation as a psychophysical process. The aim of the study is to identify patterns of interaction among motor, emotional, and cognitive components during spontaneous movement. The research analyses contemporary theoretical approaches to understanding emotional intelligence, embodiment, and improvisation, as well as concepts highlighting the role of movement as a form of thinking and self-regulation. It is shown that dance improvisation represents a holistic process in which movement, emotions, and consciousness are in continuous interaction, forming an integrated dynamic system. The role of emotional intelligence as a key mechanism enabling awareness, differentiation, and regulation of internal experience during movement is substantiated. It is concluded that dance improvisation can be considered an effective psychological practice that promotes the development of emotional sensitivity, self-regulation, and empathy.

Ключевые слова: танцевальная импровизация, эмоциональный интеллект, движение, эмоции, сознание, телесность, саморегуляция

Keywords: dance improvisation, emotional intelligence, movement, emotions, consciousness, embodiment, self-regulation

Введение

В последние десятилетия наблюдается устойчивый рост интереса к исследованию эмоционального интеллекта как одного из ключевых факторов личностного развития, психологического благополучия и эффективности межличностного взаимодействия. Наряду с этим усиливается внимание к телесно-ориентированным практикам, рассматриваемым как важный ресурс развития осознанности и регуляции эмоциональных состояний. В данном контексте особый интерес представляет танцевальная импровизация, объединяющая движение, переживание и осмысление в едином процессе.

Несмотря на значительное количество исследований, посвящённых эмоциональному интеллекту и роли телесности в психике, вопрос их интеграции в рамках импровизационной деятельности остаётся недостаточно изученным. Большинство работ рассматривает либо когнитивные аспекты эмоционального интеллекта, либо влияние танца на эмоциональное состояние, в то время как специфика импровизации как спонтанного, нелинейного и многокомпонентного процесса освещена фрагментарно. В частности, недостаточно раскрыта взаимосвязь движения, эмоций и сознания как единой системы, функционирующей в условиях неопределённости.

Танцевальная импровизация отличается от постановочной хореографии отсутствием заранее заданной структуры, что требует от исполнителя высокой степени чувствительности к внутренним импульсам, способности к их осознанию и преобразованию в движение. В этом процессе движение выступает не только как форма выражения, но и как средство познания и регуляции внутреннего опыта. Таким образом, импровизация может рассматриваться как пространство, в котором формируются и проявляются ключевые компоненты эмоционального интеллекта: эмоциональная осознанность, саморегуляция, эмпатия и социальные навыки.

Целью данной статьи является теоретический анализ взаимосвязи движения, эмоций и сознания в танцевальной импровизации, а также выявление роли эмоционального интеллекта в обеспечении целостности и эффективности данного процесса.

1.4. Взаимосвязь движения, эмоций и сознания в танцевальной импровизации

Вопрос взаимосвязи движения, эмоций и сознания в танцевальной импровизации в современном научном поле остаётся недостаточно разработанным. Несмотря на наличие отдельных исследований, посвящённых телесности, эмоциональной регуляции и осознанности, их интеграция в контексте импровизационного процесса представлена фрагментарно. В связи с этим актуальным становится теоретический анализ существующих подходов с целью выявления закономерностей взаимодействия указанных компонентов.

В рамках танцевальной импровизации движение, эмоции и сознание формируют целостную динамическую систему, в которой телесное действие выступает не только средством художественного выражения, но и способом переживания и осмысления внутреннего опыта. В отличие от заранее структурированной хореографии, импровизация предполагает возникновение движения «здесь и сейчас», что обуславливает его непосредственную связь с актуальным эмоциональным состоянием и уровнем осознанности исполнителя. Как отмечает Сергин Ю.Д., движение в данном контексте выступает медиатором между внутренним и внешним, позволяя телесной реакции опережать её когнитивную интерпретацию [1].

Анализируя роль движения в импровизации, можно отметить, что оно выполняет не только экспрессивную, но и когнитивную функцию. В ряде исследований движение рассматривается как форма телесного мышления, в рамках которого формирование смыслов осуществляется через динамику, ритм и пластическое качество действия. В отличие от подходов, в которых движение трактуется как следствие предварительно сформированной идеи, импровизационный процесс демонстрирует обратную зависимость: именно движение становится источником возникновения новых образов и смыслов, определяя дальнейшее развитие действия [2].

Эмоциональный компонент импровизации характеризуется высокой степенью включённости и непосредственности переживания. В отличие от репрезентативного подхода, предполагающего «изображение» эмоции, импровизация опирается на её проживание в телесной форме. Исследования в области контактной импровизации показывают, что эмоции выполняют регулятивную функцию, влияя на выбор, интенсивность и качество движения. При этом наблюдается эффект взаимного влияния: движение не только выражает эмоциональное состояние, но и трансформирует его, создавая непрерывный цикл обратной связи [3].

Сознание в импровизации выполняет интегративную функцию, обеспечивая согласование спонтанности и структурированности процесса. В отличие от жёсткого рационального контроля, характерного для постановочной деятельности, здесь оно проявляется как форма внимательного присутствия, направленного на отслеживание телесных и эмоциональных импульсов. В рамках интегративного подхода сознание рассматривается как многоуровневая система, включающая телесные, эмоциональные и когнитивные компоненты, которые активизируются одновременно в процессе импровизации [4].

Таким образом, пересечение движения, эмоций и сознания происходит в точках, где телесное действие становится осознанным переживанием, а эмоциональный отклик приобретает пластическую форму. Импровизация в данном контексте может быть интерпретирована как процесс самоорганизации, в котором изменение одного компонента инициирует трансформации в других. Данный подход позволяет рассматривать импровизацию как форму хореографического мышления, основанного на способности к быстрой интеграции психофизических процессов.

Значительный вклад в понимание данной взаимосвязи вносит метод «Сознание и движение», разработанный Уэйном Мак-Грегором. В рамках данного подхода импровизация рассматривается как результат взаимодействия трёх уровней: эмоционально-интуитивного, предсознательного и осознанного. Их пересечение формирует целостный акт движения, в котором телесное действие становится выражением внутреннего состояния и одновременно его осмыслением [5].

Анализ данной модели показывает, что импровизационное движение возникает не как механическое воспроизведение, а как результат непрерывного диалога между воображением, эмоциями и когнитивными процессами. В этом контексте особое значение приобретает работа с ментальными образами и вниманием. Согласно теории взаимодействующих когнитивных подсистем, лежащей в основе ряда хореографических практик, именно переключение внимания и работа с образами определяют содержание и качество движения [6].

Таким образом, движение в импровизации выступает как интегративный механизм, связывающий телесный, эмоциональный и когнитивный уровни. Эмоции обеспечивают энергетическую и регулятивную основу процесса, в то время как сознание выполняет функцию координации и осмысления.

Особое значение в данном процессе приобретает эмоциональный интеллект, который обеспечивает способность к осознанию, дифференциации и регуляции эмоциональных состояний в условиях неопределённости. В контексте танцевальной импровизации эмоциональный интеллект проявляется как чувствительность к внутренним переживаниям и способность преобразовывать их в пластическое действие. Чем выше уровень эмоциональной дифференциации, тем более вариативным и выразительным становится двигательный репертуар исполнителя.

Кроме того, эмоциональный интеллект играет ключевую роль в межличностном взаимодействии в процессе совместной импровизации. Эмпатия и социальные навыки обеспечивают формирование общего двигательного и эмоционального пространства, в котором происходит координация действий без вербальной коммуникации. Это позволяет рассматривать импровизацию не только как индивидуальный, но и как межсубъектный процесс, основанный на тонкой чувствительности к состояниям другого.

В целом, танцевальная импровизация может быть интерпретирована как специфическая психологическая практика, в рамках которой движение, эмоции и сознание образуют единую систему. Их интеграция обеспечивает не только художественное выражение, но и углублённое самопознание, что делает импровизацию перспективным объектом дальнейших междисциплинарных исследований.

Заключение

Проведённый теоретический анализ позволяет рассматривать танцевальную импровизацию как сложный психофизический процесс, в котором движение, эмоции и сознание образуют единую динамическую систему. Их взаимодействие носит взаимозависимый характер: движение выступает не только средством выражения, но и источником формирования эмоциональных состояний, эмоции регулируют качество и направленность движения, а сознание обеспечивает интеграцию и осмысление происходящего, не нарушая спонтанности процесса.

Установлено, что ключевым механизмом, обеспечивающим согласованность данных компонентов, является эмоциональный интеллект. Его развитие позволяет исполнителю более точно распознавать и дифференцировать внутренние состояния, регулировать уровень психофизиологического возбуждения и выстраивать эффективное взаимодействие с партнёром в условиях невербальной коммуникации. В этом контексте танцевальная импровизация выступает не только как художественная практика, но и как средство развития эмоциональной осознанности, саморегуляции и эмпатии.

Анализ существующих подходов также выявил недостаточную разработанность проблемы интеграции когнитивных, эмоциональных и телесных аспектов в рамках импровизационной деятельности, что указывает на необходимость дальнейших междисциплинарных исследований. Перспективным направлением является проведение эмпирических исследований, направленных на изучение влияния танцевальной импровизации на развитие эмоционального интеллекта.

Таким образом, танцевальная импровизация может рассматриваться как эффективная форма психолого-педагогической практики, обладающая значительным потенциалом в области личностного развития и психологического благополучия.

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PSYCHOLOGICAL FACTORS OF STRESS IN PUBLIC TRANSPORT USE

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Public transportation is a fundamental component of urban infrastructure; however, recent studies increasingly emphasize its impact on passengers' psychological well-being. Contemporary research highlights that stress experienced in public transport environments is shaped not only by physical conditions but also by cognitive and emotional factors, including perception of safety, uncertainty, and environmental design [1].

One of the most significant contributors to psychological stress is overcrowding. Recent empirical studies demonstrate that high-density environments are directly associated with physiological stress responses, including increased emotional arousal and discomfort [2]. In addition, crowding has been linked to aggression, anxiety, and reduced emotional regulation due to the invasion of personal space. Modern research also shows that crowd perception influences behavior indirectly through risk awareness and safety perception, especially in post-pandemic contexts [3].

Another important factor is waiting time and, more specifically, its uncertainty. Recent studies confirm that passenger satisfaction decreases significantly as waiting time increases, particularly when it is unpredictable. Furthermore, delays are associated with negative emotional states such as nervousness, fatigue, and frustration, which directly affect perceived service quality [4].

Perceived control and predictability remain central psychological mechanisms of stress. When passengers feel unable to influence their travel conditions- such as delays or overcrowding - they are more likely to experience heightened stress levels. Contemporary research also highlights the importance of real-time information systems in reducing uncertainty and improving emotional responses during travel [5].

Safety perception has become particularly relevant in recent years, especially following the COVID-19 pandemic. Studies show that increased anxiety reduces perceived safety in public transport and negatively affects overall satisfaction. Additionally, large-scale research in European cities confirms that perceptions of safety and stress significantly changed during the pandemic, reinforcing the role of psychological factors in transport use [6].

Recent literature also emphasizes the role of social and environmental design. For example, studies on transport environments show that poorly maintained or crowded spaces increase stress, while improved design and amenities can significantly enhance well-being. Moreover, social

norms and interactions - such as fear of judgment in shared spaces - can create additional psychological tension among passengers [7].

Recent studies also emphasize the role of environmental factors such as noise, temperature, and air quality in shaping psychological stress in public transport. Elevated noise levels and poor ventilation have been associated with increased irritability, fatigue, and reduced concentration among passengers. Another important aspect is the cumulative effect of daily commuting stress. Research shows that repeated exposure to stressful transport conditions can lead to long-term psychological consequences, including chronic fatigue, decreased life satisfaction, and burnout symptoms [8]. Regular commuters are particularly vulnerable, as daily stressors accumulate over time and negatively affect both mental health and overall quality of life.

Digitalization of transport systems has also become a significant factor influencing passengers' psychological experience. The availability of mobile applications and real-time tracking systems reduces uncertainty and improves perceived control, which in turn lowers stress levels [9]. However, technological solutions may also create new sources of stress, such as information overload or frustration caused by inaccurate data. Finally, social interactions within public transport environments contribute to psychological tension. The presence of unfamiliar individuals, violation of social norms and the risk of conflict situations can increase anxiety and emotional tension [10].

In this context, public transport can be viewed not only as a physical space but also as a complex social environment where psychological comfort depends on both individual and collective behavior. Overall, modern research suggests that psychological stress in public transport is a complex and multifactorial phenomenon influenced by environmental conditions, cognitive perception, and social context. Addressing these issues requires a human-centered approach that integrates infrastructure improvements with psychological considerations, including predictability, comfort, safety, and access to information.

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Cognitive and emotional impairments in volatile substance abusers

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Abstract: Volatile substance use is common in low-income socioeconomic groups, those with a history of crime or imprisonment, depression, suicide attempts, antisocial attitudes, school absenteeism, family disintegration or conflict, parental dependence, peer dependence, a history of abuse, violence or other substance use, and in isolated communities. The duration and frequency of volatile substance use increase morbidity and mortality. A significant exception is sudden respiratory death. It was reported that 22% of volatile substance users who experienced sudden death were using volatile substances for the first time. Sudden death is the most common type of death related to volatile substances. Sudden deaths are attributed to sudden cardiac arrhythmias resulting from hydrocarbons sensitizing the myocardium to epinephrine by increasing catecholamine release. Although thinner addiction is a disorder whose frequency is increasing in the world, its long-term consequences are underreported. Many patients with thinner addiction lose their functionality due to the effects of this substance. In addition, the fact that it causes muscle weakness in the upper motor neuron type is significant in showing that the neurodegenerative process is related to the continued use of thinner. Cognitive damage and psychotic disorder are consistent with white matter damage. Given the serious and sometimes irreversible consequences of volatile substance addiction in the chronic phase, early medical and psychosocial interventions in patients appear to be quite important.

Keywords: drug users, volatile substance abusers, cognitive impairment, neurodegenerative process

Substance abuse disrupts the brain's reward, motivation, and decision-making mechanisms (especially in the frontal cortex), leading to serious cognitive impairments. Difficulty concentrating, memory problems, impaired decision-making, loss of impulse control, and permanent structural brain changes (atrophy) are common. These conditions result from permanent changes in brain structure that occur over time due to chronic substance use (Williams, 2007).

Medical problems in chronic drug and volatile substance users can be grouped as follows: 1) Muscle weakness; 2) Gastrointestinal problems such as pain, nausea, vomiting, hematemesis; 3) Renal failure often accompanied by serious electrolyte imbalances; 4) Cardiomyopathy; 5) Liver damage; 6) Pulmonary hypertension, respiratory distress such as increased airway resistance and acute respiratory distress; 7) Hematopoietic disorders (increased carboxyhemoglobin levels, methemoglobinemia, hemolytic anemia, aplastic anemia, even acute myelocytic leukemia) (Williams, 2007). Chronic volatile substance use can cause neurological symptoms and mood disorders such as fatigue, tremor, impaired coordination, peripheral neuropathy, paresthesia, cerebellar dysfunction, parkinsonism, optic neuropathy, cranial neuropathy (usually cranial nerve V and cranial nerve VII), chronic encephalopathy, dementia (leaded gasoline-induced dementia or toluene-induced white matter dementia). Neuropsychiatric dysfunction is consistent with white matter damage. Brain imaging studies have shown widespread atrophy of the cerebrum, cerebellum, and brainstem, ventricular dilation, and sulci enlargement in chronic use. Periventricular, subcortical (basal ganglia and thalamus), and white matter dysfunction is more pronounced. Demyelination, hyperintensity, callosal thinning, and deletion at the gray-white

matter boundary were found in these cases. The damage revealed by brain imaging studies in volatile substance addicts is greater and more severe than in other substance addictions. Bilateral blood flow in the prefrontal cortex was observed in volatile substance addicts, and apathy was associated with clinical avolition (Ives, 2000).

Seventy percent of volatile substance users are diagnosed with a lifetime mood, anxiety, and personality disorder. Major depression and suicide risk, alcohol dependence, prison life, and memory impairment are common in volatile substance use. While most of the resulting symptoms are reversible, chronic toluene use, in particular, can cause changes similar to psychotic findings in schizophrenia (Ozturk, 2008). The most common symptoms are delusions and hallucinations, with auditory and visual hallucinations more frequently associated with paranoid delusions and persecutory themes. Volatile substance use is significantly more common in those with street life than in those without. Volatile substances are used more than other substances in those with street life, and self-harm behavior is more frequent. Mood disorders, anxiety disorders, and some personality disorders have been found to be more common in the parents of adolescents who use volatile substances. Substance abuse is a type of addiction that is more common in children and adolescents and has serious medical, neurological, and psychiatric consequences. It can be more severe in disadvantaged groups and those who live on the streets (Sakai, 2009).

Borderline hemoglobin levels and slightly lower hematocrit levels are expected hematological changes in volatile substance addictions. Cranial MRI results showing sulci widening, atrophy, and white matter damage are consistent with the demential process and findings related to the destruction caused by volatile substances in the central nervous system. The psychotic symptoms in the patient were most frequently persecutory paranoid delusions. The patient's good response to olanzapine, an atypical antipsychotic suggested as a suitable choice for this patient, may be due to the positive effects of this preparation on mood. It was decided to start antidepressants due to depressive mood and social withdrawal. Some of the patient's depressive symptoms may be due to the disruptive effects of volatile substance use. However, since feelings of worthlessness, loss of interest and desire, feelings of inadequacy, and depressive mood were prominent, the diagnosis of depression could not be ruled out. Mirtazapine was chosen because it can be effective for complaints of loss of appetite and insomnia (Ozturk et.al.,2010).

The acute phase and intoxication symptoms of volatile substance addiction are well known. However, as the risk of addiction decreases over the years, the effects of the chronic phase are encountered less frequently. Over the years, both volatile substance use and the associated risk of addiction decrease. The course of our case includes many components of the typical course of chronic volatile substance addiction. The sudden death of our patient's brother, who was also a volatile substance addict and lived on the streets, and the patient's own neurological, medical, and mental deterioration, culminating in cognitive decline in his 30s, along with a psychotic and depressive state, highlight the severe consequences of volatile substance use. Majority of patients can't go out at all in the last ten years except to take thinner, is unable to work, and cannot develop meaningful interpersonal relationships.

Substance abuse impairs cognitive function, negatively impacting executive functions, memory, attention, and decision-making processes. This leads to significant problems in daily life, work, and social interactions. Neuroimaging studies show that this disorder causes structural and functional changes in brain regions such as the prefrontal cortex, hippocampus, and striatum. Impaired executive function leads to problems with impulse control, which leads to continued substance use. Depending on the type of substance, varying degrees of impairment in cognitive functions such as attention, memory, and cognitive flexibility are observed. Impaired cognitive function complicates treatment and increases the risk of relapse. Although partial improvement in some cognitive functions may be observed after prolonged abstinence from psychoactive substances, impairments in executive functions and decision-making processes may be irreversible (Ogel et.al,

2001). Therefore, drug addiction research should focus not only on managing withdrawal symptoms but also on strategies for protecting cognitive function.

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Journalism

Research on the Content Production and Dissemination Strategies of Governmental Short Videos — Taking the Douyin Platform as an Example

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Аннотация: Производство и распространение государственных коротких видеороликов на платформе Douyin демонстрируют их уникальную роль в условиях цифровизации. В данной статье на примере платформы Douyin, с использованием теоретических подходов коммуникации, систематически исследуются стратегии производства и распространения государственных коротких видеороликов. Исследование с позиций многообразия типов контента, функции постановки повестки дня и технологической поддержки выявляет уникальные преимущества государственных коротких видеороликов в снижении барьеров доступа к информации, повышении ее привлекательности и усилении эффективности распространения. Одновременно анализируется влияние дружелюбного языка общения, оптимизации коммуникационного контекста и инноваций аудиовизуальных технологий на повышение эффективности распространения. Результаты исследования показывают, что государственные короткие видеоролики не только эффективно способствуют взаимодействию между государством и населением, повышают доверие к власти, но и обеспечивают новые практические пути и теоретическую поддержку для распространения государственной информации, предлагая новый взгляд на инновационное развитие коммуникации государственных сообщений.

Ключевые слова: государственные короткие видеоролики, производство контента, постановка повестки дня, стратегии распространения

Abstract: The content production and communication practices of government short videos on the Douyin platform demonstrate their unique role in the digital context. Taking the Douyin platform as the research object and combining communication theory analysis, this paper systematically explores the content production and communication strategies of government short videos. From the perspectives of diversified content types, agenda-setting functions and technological empowerment, the study reveals the unique advantages of government short videos in lowering the threshold for information access, enhancing information appeal and improving communication effects. Meanwhile, it analyzes the boosting effect of a people-friendly tone, optimized communication context and audio-visual technological innovation on communication efficiency. The study finds that government short videos not only effectively promote government-public interaction and enhance government credibility, but also provide new practical paths and theoretical support for the dissemination of government information,

offering a new perspective for the innovative development of government information communication.

Keywords: government short videos, content production, agenda setting, communication strategies

1 Введение

Согласно «Доктору о больших данных Douyin», на конец 2018 года в Douyin зарегистрировались уже 5724 государственных аккаунта, и государственные короткие видеоролики постепенно становятся новым медиа и новой площадкой для государственных коммуникаций. В последние годы государственные новые медиа как важный канал для связи с населением, обслуживания населения и объединения людей значительно повысили свою способность к распространению, руководству, влиянию и доверию. Благодаря производству контента государственные новые медиа могут эффективно создавать ситуации для участия населения, способствуя привлечению внимания, восприятию и распространению государственной информации среди населения. Однако развитие государственных новых медий все еще сталкивается со многими проблемами в коммуникации, включая недостаток инноваций в контенте, низкую степень участия пользователей и недостаточную способность реагировать на общественные мнения. Однако при оценке общего экологии распространения информации в сети сейчас большинство государственных новых медиа имеют слабую способность к распространению, руководству, влиянию и доверию, что не соответствует их огромному масштабу, авторитетному образу и ключевому положению, а также не позволяет им играть важную роль в инновациях социального управления и формировании общественного консенсуса. Поэтому необходимо осуществить инновации для выхода за рамки целевой аудитории и повысить эффективность распространения, чтобы лучше удовлетворить потребности населения и требованиям развития.

Как новая форма государственных коммуникаций, государственные короткие видеоролики благодаря своему близкому к населению способу выражения и характеристикам распространения, соответствующим привычкам просмотра широкой публики, постепенно становятся важным мостом между правительством и населением. В контексте информационного взрыва внимание населения все чаще фрагментируется: люди предпочитают быстро получать новости и государственную информацию в свободное от дел время через короткие видеоролики и другие формы. Такая особенность просмотра «в любое время и в любом месте» не только снижает порог доступа к информации, делая традиционно сложную и непонятную государственную контент более понятной и ясной, но и значительно усиливает привлекательность и воздействие информации благодаря аудиовизуальным средствам. В последние годы контент государственных аккаунтов, созданных официальными основными медиа, является разнообразным и многогранным. Например, «People's Daily», «CCTV News», «People's Network», «Xinhua News Agency», «Guangming Daily», «China Daily» и другие — эти государственные аккаунты создали модель интерактивных коммуникаций, ориентированную на потребности населения, что способствует здоровому, упорядоченному и эффективному развитию государственных новых медиа и имеет важное теоретическое и практическое значение.

Introduction

According to the Douyin Big Data Report, by the end of 2018, 5,724 government accounts had been established on the Douyin platform, and government short videos had gradually emerged as a new medium and frontier for government communication. In recent years, as a critical channel for the government to engage with, serve, and mobilize the public, government new media has significantly strengthened its communication capacity, guiding influence, overall impact, and public credibility. Through content production, government new media can effectively foster a context for public participation, thereby encouraging the public to pay attention to, accept,

and share government information.

Nevertheless, the development of government new media still confronts numerous communication challenges, including inadequate content innovation, low levels of user engagement, and insufficient capacity to respond to public opinion. From the perspective of the overall ecosystem of online information dissemination, most government new media currently exhibit relatively weak communication capacity, guiding influence, impact, and credibility—discrepancies that are inconsistent with their large scale, authoritative status, and key role, and which hinder their ability to support innovations in social governance and the building of social consensus. Consequently, "circle-breaking" innovations are required to enhance communication effectiveness and better align with public needs and the demands of the times.

As an emerging form of government communication, government short videos have increasingly become a vital bridge between the government and the public, characterized by their people-oriented expression and alignment with mainstream viewing habits. Amid the information explosion, public attention has become increasingly fragmented, with individuals tending to use fragmented time to access news and government information quickly through short videos and other formats. This "anytime, anywhere" viewing experience not only effectively lowers the barriers to information access, rendering traditionally complex and obscure government content clearer and more accessible, but also significantly boosts the appeal and emotional resonance of information through audiovisual means.

In recent years, government accounts operated by official mainstream media—such as People's Daily, CCTV News, People.cn, Xinhua News Agency, Guangming Daily, and China Daily—have featured rich and diverse content. These accounts have established a public demand-driven interactive communication model, which promotes the healthy, orderly, and efficient development of government new media and carries important theoretical and practical significance.

Chapter 1 Content Production: Diverse Types and Agenda-Setting

Analysis of the Diversification of Government Short Video Types

According to the data in Table 1 as of October 20, 2024, the performance of government-affiliated accounts on the Douyin platform shows significant disparities. People's Daily ranks first in both total video volume and likes, with 7,023 videos posted garnering 13.44 billion likes, indicating high user attention and interactivity for its content on the platform. Although CCTV News has fewer videos than People's Daily, it boasts 160 million followers and 9.39 billion likes, reflecting its strong user base and platform influence, particularly a distinct advantage in attracting a large number of followers.

Table 1 Distribution of Short Videos from Government-Affiliated Accounts

Government-Affiliated Account Name	Total Number of Videos	Total Likes	Number of Followers	Most-Liked Video and Its Like Count
People's Daily	7023	13.44 billion	170 million	<i>Armed Police Force Vanguard's March in Step with Eyes Blindfolded</i> (35,359,000 likes)
CCTV News	10,000	9.39 billion	160 million	<i>"Father of Hybrid Rice" Yuan Longping Passes Away</i> (34,410,000 likes)
People's Daily Online	14,000	3.78 billion	66,346,000	<i>Female Soldiers Shed Tears After the National Day Military Parade!</i> (23,537,000 likes)
Xinhua News Agency	20,000	1.88 billion	69,315,000	<i>Train Conductor Rebukes Woman Smoking in High-Speed Rail Toilet, Triggering Alarm</i> (16,431,000 likes)
Guangming Daily	4204	1.27 billion	30,577,000	<i>Let Me Tell You: I Am a Chinese Citizen, There Will Be No Problem with My COVID-19 Test Results!</i> (19,141,000 likes)
China Daily	15,000	1.70 billion	37,232,000	<i>American Residents Lash Out at U.S. Media for Concealing Information</i> (16,544,000 likes)

In comparison, People's Daily Online has posted a relatively small number of videos, yet its likes and follower count still demonstrate strong appeal, suggesting sound performance in content quality and user stickiness. Additionally, Xinhua News Agency, Guangming Daily, and China Daily show relatively weaker performance in terms of likes and followers, which may imply room for improvement in content innovation, interactivity, or communication strategies for these government-affiliated accounts. To further enhance their influence, they may need to adjust their approaches to attracting user attention and improving content quality to adapt to platform changes and user demands.

A clear classification trend has emerged in the content dissemination of multiple government-affiliated accounts, mainly encompassing the following four categories:

First, international news category. For instance, the video titled *American Residents Lash Out at U.S. Media* posted by the government-affiliated account of China Daily, the second-most-liked video on this account, showcases American citizens' criticism of their domestic media for concealing information about the novel coronavirus, emphasizing China's stance and image in international public opinion. By adopting communication strategies aligned with the cognitive and acceptance habits of international audiences, the video effectively fostered the international community's understanding and recognition of China's epidemic prevention and control measures. Another example is the video *Many American Faces Appear in Hong Kong's Violent Protest Marches* released by Guangming Daily's government-affiliated account. Such reports, through in-depth analysis and commentary, focus on China's attitudes and positions in international affairs, elevating China's international discourse power and influence. This strategy not only helps shape China's image in the global public sphere but also enhances diverse perspectives among international audiences through information selection and framing,

promoting cultural exchanges and the building of global consensus.

Second, domestic news category. For example, in a video from Xinhua News Agency's government-affiliated account, *A Passing Female Nurse Rescues a Collapsing Passenger, Restoring His Heartbeat*, the content centers on domestic social news, shifting the perspective to ordinary people's lives. By focusing on social news events, it highlights the heroic acts of ordinary citizens in public emergencies. Such videos convey positive social values, contributing to the construction of a harmonious society, while also demonstrating the country's capabilities and efficiency in responding to emergencies, further strengthening the audience's sense of social identity and belonging.

Third, national defense and military category. For instance, the video *Female Soldiers Shed Tears After the National Day Military Parade!* from People's Daily Online's government-affiliated account adopts military documentary-style reporting. By showcasing the training scenes of China's military and the heroic deeds of female soldiers, it enhances public understanding of the importance of national security and military strength. High-quality footage and emotional editing techniques reinforce citizens' patriotism and national pride.

Fourth, culture and people's livelihood category. For example, the video *First Russian Aircraft Arrives in Wuhan to Assist in the Fight Against COVID-19* from China Daily's government-affiliated account focuses on major national events and livelihood hotspots. By reporting international aid and cooperation, it showcases the country's responsibility and commitment in global public health emergencies, while also paying attention to people's living conditions and needs during the epidemic. It demonstrates the country's emphasis on people's livelihood and its determination to improve it, enhancing public understanding and support for national policies and promoting social harmony and stability.

A Study on Agenda-Setting in Government-Affiliated Short Videos

Agenda-setting Theory is a key concept in political communication, proposed by Maxwell McCombs and Donald Shaw in 1972. The theory holds that through selective reporting, the media can influence the public's attention to and cognitive priority of certain issues [3]. In the field of government-affiliated short video communication, agenda-setting provides important theoretical support for content production and dissemination. By means of the media's selective coverage of major news events, the government can effectively guide the public to focus on specific issues, transform the traditional official discourse style, and improve the dissemination effect of government information. This transformation makes the communication of government information more vivid and intuitive, and easier for the public to understand and accept.

For example, the video *Armed Police Force Vanguard Marches in Step with Eyes Blindfolded* released by People's Daily successfully guided public attention to military training by selecting this topic and combining delicate audio-visual elements (such as sweat at the corners of the eyes, orderly steps, and sonorous music). This form of reporting not only strengthens the importance of national security and military strength, but also enhances the public's awareness and sense of participation regarding this issue.

In addition, the video *"Father of Hybrid Rice" Yuan Longping Passes Away* issued by CCTV News conveyed condolences to Academician Yuan Longping through sad background music, images of his smile, and the transition from color to black-and-white frames, while also reinforcing the public's understanding of food security and the contributions of scientists. This form not only delivers information but also enhances public participation and identity through audio-visual means, which is of great significance for improving the efficiency of government information dissemination, strengthening the government's image, and promoting government-public interaction.

Chapter 2 Communication Strategies of Government-Affiliated Short Videos

Content Design and Information Presentation

In the operation of government-affiliated short video accounts, accurately positioning the audience and establishing a distinct content style is an essential requirement [4]. On the one hand, users pay significant attention to the timeliness of news, which has become an important indicator for measuring communication effectiveness. By delivering concise and clear information, combined with intuitive visual elements and easy-to-understand textual expressions, users can quickly grasp the core content of news, avoiding lengthy narratives, thereby improving news acceptance and effectively capturing users' attention. On the other hand, adopting a contextualized presentation approach, integrating the unique characteristics of short videos, and incorporating entertaining elements can not only enhance the audience's sense of participation and interest but also significantly boost the effectiveness of information dissemination. Such a multi-dimensional presentation strategy contributes to the efficiency and appeal of information transmission.

In the construction of government-affiliated short videos, content creation should not only deeply explore official information and extensive news resources but also ensure close relevance to the public. According to the Cognitive Surplus Theory, users' motivations for participating in short video content production include satisfying the needs for identity recognition and self-actualization, being driven by social contagion in tacit knowledge production, being inspired by creative enthusiasm in explicit knowledge production, and having strong social demands for content production and dissemination. These factors constitute the original driving force for users to participate in short video content creation. Therefore, the content design of government-affiliated short videos should fully leverage these motivations to enhance user engagement and the communication effectiveness of content [5]. Narrative techniques should pursue a combination of humor and profundity, as well as the expression of clear stances. Meanwhile, based on precise positioning, timely capturing and responding to social hotspots and continuously updating content are required. This demands the discovery and cultivation of innovative talents, the building of an innovative team, and the full stimulation of creative potential to produce short video content that is both lively and positive.

Voice Shaping and Optimization of Communication Context

In the content production and communication strategies of government-affiliated short videos, voice shaping is one of the key factors for effective communication. The adoption of a people-friendly and accessible tone helps transform policy information from "hard propaganda" into more acceptable "soft information," making policy content closer to people's livelihood and infused with a human touch. According to the proximity principle in social psychology, when information is presented in a manner closer to the audience's daily life, the audience is more likely to resonate, thereby improving information acceptance and communication effectiveness.

In terms of optimizing the communication context, user interaction and guidance represent important means to enhance the communication effect of government-affiliated short videos. Setting relevant topics in the comment section can stimulate users' enthusiasm for participation, and further promote the wide dissemination of information through interactive behaviors such as commenting, sharing, and liking. This not only strengthens the communication effect of news but also builds an emotional bridge between the government and the public. The enhancement of such interaction helps improve public support and trust in government actions. Effective communication is not merely a one-way transmission of information, but a two-way process involving feedback and interaction.

Technology Empowerment and Improvement of Communication Efficiency

Strengthen innovative reporting of virtual reality (VR) news in government-affiliated short videos. By utilizing 360-degree panoramic cameras and physical equipment, an immersive "being there" experience is created, transforming the audience from traditional "onlookers" into

"witnesses" at the news scene. Different from the traditional linear communication model, VR technology enables users to independently choose their viewing angles and interact with characters in the report, offering the possibility of multi-dimensional presentation. This narrative mode shifts from a "qualitative perspective" to a "quantitative perspective," providing a new dimension for the construction of news discourse. Specifically, the perspective-switching feature of embodied communication presents new opportunities for VR news reporting: users participate in news events as first-person witnesses, gaining a deeper understanding and experience of the news content. Meanwhile, embodied communication also enables VR news to break through communication barriers, establish a direct user-news connection, and endow news reporting with new forms of expression [6].

Strengthening the application of drone technology in the field of short video news has brought remarkable innovations to news coverage. Drones feature a broad field of vision and unique angles, capable of overlooking news scenes from high altitudes and providing audiences with a brand-new visual experience. Their adaptability and flexibility allow shooting in harsh environments and complex terrains, making them particularly suitable for panoramic scenes and major event coverage, thus effectively ensuring journalists' safety. Furthermore, by transmitting captured images and videos in real time, drone technology can be integrated with mobile live streaming to realize the innovative "drone + live streaming" mode. When incorporated into short video live broadcasts, this new model strengthens connections with users and accelerates the rapid dissemination and popularization of news.

Conclusion

In the digital era, government-affiliated short videos have become an important bridge for communication between the government and the public. Relying on people-oriented expressions and innovative communication strategies, they have effectively enhanced the dissemination, guidance, influence, and credibility of government information. Taking the Douyin platform as an example, this paper systematically analyzes the content production and communication strategies of government-affiliated short videos, and reveals the key roles of diversified content creation, precise agenda-setting, and technology empowerment in improving communication effectiveness. By lowering the threshold for information access and enhancing information appeal, government-affiliated short videos have promoted the efficient dissemination of government information and played a significant role in government-public interaction and government image building. This not only provides theoretical support and strategic guidance for the practice of government new media communication, but also offers an important reference for the future development of government-affiliated short videos. In the future, government-affiliated short videos will play a more crucial role in the modernization of social governance, providing new possibilities and practical paths for building a harmonious society and innovating social governance.

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A Survey and Analysis of the Impact of Cultural Hegemony in Film and Television Drama Works on Chinese Audiences

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Abstract

This study explores the cultural impacts of overseas film and television drama works on Chinese audiences and their perceptions of cultural hegemony. It conducts an in-depth analysis of the degree of cultural integration of overseas film and television dramas among Chinese audiences. The results show that contemporary Chinese audiences do not simply equate the dissemination of overseas film and television dramas with cultural hegemony, but hold an objective attitude of being open and inclusive while regarding such impacts as a balance of advantages and disadvantages. This reflects that against the backdrop of cultural confidence construction, audiences have formed a natural cultural barrier. The research conclusions provide empirical support for domestic film and television dramas to enhance their competitiveness and express cultural confidence in the context of globalization.

Keywords: film and television drama; cultural hegemony; Chinese audiences; cultural identity; film and television drama communication

Introduction

With the development of the film and television drama industry and media convergence, overseas film and television drama works have been deeply integrated into the cultural and recreational lives of Chinese audiences through diverse communication channels, and the associated issues of cultural export and cultural hegemony have thus become important topics in the field of cultural research. As an important carrier of cultural communication, film and television drama works not only bear the aesthetic value of audio-visual art, but also embody specific values and cultural logic. Their cultural expressions not only bring diverse cultural experiences to local audiences, but also pose potential challenges to the construction of local cultural identity and the development of the cultural industry.

Overseas culture disseminated through film and television drama works exerted a certain influence on Chinese audiences' values and lifestyles in the early years. To explore Chinese audiences' current perceptions and attitudes towards the dissemination of overseas film and television dramas and the phenomenon of cultural hegemony, this study launched a special investigation from three dimensions—the viewing characteristics of overseas film and television dramas, audiences' cognitive attitudes, and expectations for the development of domestic film and television dramas—by combining quantitative and qualitative research methods. It systematically sorted out audiences' exposure to mainstream overseas film and television dramas from the United States, South Korea and other countries, as well as their judgments on cultural infiltration and cultural hegemony and demands for the development of the local cultural industry. The research results aim to present the cultural cognitive characteristics of contemporary audiences against the backdrop of multicultural integration, provide practical references for domestic film and television dramas to cope with the strong influence of overseas ones and achieve innovation while upholding traditions, and meanwhile offer targeted insights for the communication of local

culture and the construction of cultural confidence.

Research Objectives

This study centers on the impact of cultural hegemony in overseas film and television drama works on contemporary Chinese audiences. Integrating quantitative data from questionnaire surveys with qualitative analysis from semi-structured interviews, it conducts a systematic investigation into audiences' exposure behaviors, cognitive attitudes and perceptions of cultural impacts regarding overseas film and television dramas. The research aims to achieve multi-dimensional objectives and provide empirical evidence for understanding the practical manifestations and response paths of cultural hegemony in film and television drama communication, with the specific research goals divided into theoretical and practical dimensions.

At the theoretical level, first, this study seeks to sort out the current dissemination status of overseas film and television drama works in China, clarify the frequency, main types and sources of audiences' exposure to such works, and conduct a quantitative analysis of their communication characteristics in the cultural consumption market, thus filling certain gaps in the empirical research on the cultural communication of overseas film and television dramas from the perspective of local audiences. Second, it explores the cognitive dimensions of audiences towards cultural hegemony in overseas film and television drama works, including the cognitive differences in the sources of influence, value export behaviors and cultural infiltration effects of representative overseas types such as Hollywood films and Korean dramas. It also defines the specific manifestations of cultural hegemony in film and television drama communication, enriching the local practical research on the theory of cultural hegemony in film and television dramas. In addition, combined with interview data, the study explores audiences' subjective perceptions of the cultural impacts of overseas film and television dramas, analyzes the causes of individual differences in the influence of cultural hegemony, and improves the audience cognition research system for the cross-cultural communication of film and television drama culture.

At the practical level, first, this study aims to clarify the specific impacts of overseas film and television drama works on domestic audiences, including their guiding effects on values, aesthetic orientations, lifestyles and consumption concepts, as well as their potential impacts on local cultural identity, so as to objectively judge the advantages and disadvantages of the cultural communication of overseas film and television dramas. Second, it summarizes audiences' expectations and suggestions for domestic film and television dramas to cope with the strong influence of overseas ones, providing targeted guidance for the creation and development of domestic film and television dramas. Finally, based on the research results, the study proposes a film and television drama cultural communication strategy featuring both openness and local characteristics. It offers practical references for balancing cross-cultural film and television drama exchanges and local cultural protection, enhancing the cultural competitiveness of domestic film and television dramas, and supporting the expression and communication of cultural confidence of local film and television dramas in the context of globalization. Meanwhile, this study also attempts to provide feasible ideas for avoiding the negative impacts of cultural hegemony in overseas film and television dramas, building a healthy film and television drama cultural ecology, and promoting the high-quality communication and development of local film and television drama culture.

Methods

This study adopted a mixed-methods approach, combining quantitative questionnaire surveys with qualitative semi-structured interviews. Centering on the cultural hegemony in film and television drama works, the research was carried out from the dimensions of audiences' exposure behaviors, cognitive attitudes and perceived impacts, so as to ensure the objectivity, quantitateness and in-depth nature of the research results. These two research methods complement and corroborate each other, laying a solid empirical foundation for the research

conclusions.

Questionnaire Survey Method

The questionnaire survey was conducted among Chinese residents who had exposure to overseas film and television drama works, with a positive age distribution and an even regional distribution. Questionnaires were distributed online, and a total of 59 valid questionnaires were collected by the time of data statistics for this paper, with a 100% valid recovery rate. Around the research theme, the questionnaire was designed with 10 core questions, including single-choice and multiple-choice questions, and the content was divided into four parts: first, exposure behaviors to overseas film and television dramas, including viewing frequency, as well as the main sources and types of overseas film and television dramas accessed; second, cognition of the influence of overseas film and television dramas, focusing on exploring the sources of the global influence of Hollywood film and television drama works; third, perceptions of cultural hegemony and cultural impacts, involving attitudes towards the value export of overseas film and television dramas, their guidance on lifestyles, and the weakening of local cultural identity; fourth, suggestions for the development of domestic film and television dramas, investigating audiences' expectations for domestic film and television dramas to cope with the strong influence of overseas ones. Descriptive statistical methods were used to analyze the questionnaire data. By calculating the subtotals and proportions of each option, the overall cognitive characteristics of audiences towards the cultural hegemony in overseas film and television dramas were presented quantitatively, providing quantitative empirical evidence for the research.

Semi-structured Interview Method

On the basis of the questionnaire survey, five typical interviewees were selected for in-depth semi-structured interviews to further explore their subjective perceptions and in-depth cognition of the cultural hegemony in overseas film and television dramas. All interviewees had the experience of watching overseas film and television dramas, loved foreign film and television drama culture, and had in-depth exposure to and thinking about both overseas and domestic film and television dramas. Their identities and experiences could provide personalized and in-depth qualitative data for the research. The interview was designed with 6 core open-ended questions, covering the perceived strong cultural influence of overseas film and television dramas, the influence paths of their value export and lifestyle guidance, subjective feelings about the phenomenon of cultural hegemony, impacts on local cultural identity, attitudes towards addressing cultural hegemony, and ways to balance the love for overseas film and television dramas and the identification with local culture.

Research Data Integration

This study systematically integrated the quantitative data from the questionnaire survey and the qualitative data from the semi-structured interviews, combining the quantitative overall cognitive characteristics with the qualitative in-depth individual perceptions. It not only presented the general attitudes of audiences towards the cultural hegemony in overseas film and television dramas from a macro perspective, but also explored the individual differences and specific manifestations of the impacts of cultural hegemony from a micro perspective, thus ensuring the comprehensiveness, objectivity and scientificity of the research conclusions.

Results

A special survey was conducted on the issue of cultural hegemony in film and television drama works, with a total of 59 valid questionnaires collected. The survey was carried out from three dimensions: the viewing characteristics of overseas film and television dramas, audiences' cognitive attitudes, and expectations for the development of domestic film and television dramas, fully sorting out audiences' views on the dissemination of overseas film and television dramas and the phenomenon of cultural hegemony. The integrated analysis of the survey results is as follows:

The survey shows that overseas film and television dramas have been deeply integrated

into audiences' cultural and recreational lives, with their viewing characteristics presenting obvious centralization. In terms of viewing frequency, 47.46% of the respondents reported watching overseas film and television dramas "occasionally", accounting for the absolute majority; 22.03% watched them "often" and another 22.03% "rarely"; the proportions of those who watched them "almost every day" or "hardly ever" were both less than 10%, showing an overall characteristic of being high in the middle and low at both ends. In terms of content sources, American and Korean film and television dramas occupy an absolute dominant position: the exposure rates to Hollywood films, American dramas and Korean film and television dramas reached 59.32%, 50.85% and 50.85% respectively, followed by Japanese anime and film and television dramas (38.98%). The exposure to European film and television dramas and works from other regions was relatively low, reflecting that the overseas film and television drama content accessed by audiences is highly concentrated in regions with mature industrialization and strong cultural proximity.

Audiences have formed a rational and hierarchical cognition of the influence, cultural export and hegemony phenomenon of overseas film and television dramas. Regarding the global influence of Hollywood, 62.71% of the respondents believed that its core lies in the powerful production technology and special effects, and 23.73% recognized the attractiveness of its stories, while the recognition of factors such as monopoly of publicity channels, value export and star effect was all below 6%. It is evident that audiences regard solid production strength as Hollywood's core competitiveness. At the same time, 67.79% of the respondents agreed that Hollywood imperceptibly exports Western values, indicating that audiences can clearly perceive the cultural infiltration behind its technical carrier. As for the influence of Korean dramas, 47.45% of the respondents believed that they have a certain impact on aesthetics, lifestyles and other aspects, yet 45.76% held a neutral attitude. Moreover, only 32.2% of the respondents agreed with the idea of "imitating lifestyles in overseas film and television dramas", which shows that the influence of Korean dramas mostly stays at the level of superficial perception and has not formed an in-depth impact on audiences' core cognition.

In terms of the core cognition of local cultural identity and cultural hegemony, the respondents showed a mentality of being concerned but not extreme. 42.37% of the respondents believed that overseas film and television dramas "may weaken" local cultural identity, only 10.17% thought they "will definitely" do so, and 20.34% held the view that they "are unlikely to" have such an effect. This reflects that audiences have concerns about the potential challenges faced by local cultural identity, but are not overly anxious. As to whether the global popularity of American and Korean film and television dramas amounts to cultural hegemony, 40.68% of the respondents held a neutral attitude, 33.89% agreed, and 25.42% disagreed, indicating that audiences are cautious in judging cultural hegemony and do not simply equate the dissemination of overseas film and television dramas with cultural hegemony. In the evaluation of the overall influence of overseas film and television dramas, 72.88% of the respondents believed that their influence is "basically a balance of advantages and disadvantages", only 6.78% regarded it as "cultural invasion with more disadvantages than advantages", and 15.25% considered it "a cultural enrichment with more advantages than disadvantages", which demonstrates that audiences have an objective and comprehensive judgment on the influence of overseas film and television dramas.

Based on the above cognition, the respondents put forward relatively unified development demands for domestic film and television dramas, focusing on strengthening internal capabilities and embracing openness and inclusiveness. 76.27% of the respondents hoped that domestic film and television dramas would improve production standards and tell Chinese stories well, and 71.19% suggested enhancing cultural confidence and exporting local values. These two points have become the top expectations, showing that audiences believe the core development direction of domestic film and television dramas is to upgrade their own production strength and cultural core. At the same time, 49.15% of the respondents supported the rational introduction of overseas film

and television dramas without blind rejection, only 28.81% thought it necessary to strengthen supervision to reduce cultural infiltration, and a mere 1.69% held an indifferent attitude. This reflects that audiences oppose seclusion and rejection, and expect domestic film and television dramas to absorb advanced experience and achieve their own development through benign competition with overseas film and television dramas.

Discussion

A comprehensive analysis reveals that the surveyed audiences as a whole demonstrate a state of confidence in local culture and inclusiveness toward foreign cultures, which is attributable to China's cultural revitalization policies over the past decade. From the rise of national trends to the renewed popularity of Hanfu, Chinese culture has forged a natural psychological barrier in the minds of the Chinese people, enabling them to embrace foreign cultures without compromising traditional culture.

Notably, the data indicates a relatively significant influence of Korean film and television drama culture on Chinese audiences. This is because China and South Korea both belong to the East Asian cultural circle, and Korean culture has been deeply influenced by Chinese culture throughout history. Many cultural symbols are expressed within a shared contextual framework and bear certain similarities. Consequently, audiences within the same cultural circle are more susceptible to such influences, a phenomenon closely linked to the meanings, national sentiments and emotional connotations embodied by these cultural symbols.

Several limitations have emerged during the data analysis, including the insufficient sample size and the narrow age range of the survey participants, which have constrained the generalizability of the research findings.

Overall, this survey reflects that against the backdrop of multicultural integration, contemporary audiences maintain a certain degree of cultural vigilance alongside an open and inclusive attitude toward overseas film and television dramas. For the development of domestic film and television dramas, they place their hopes on the core of enhancing intrinsic strength, and achieving innovation while upholding traditional roots on the basis of cultural confidence.

Conclusion

This study found through surveys that foreign film and television dramas have been deeply integrated into the cultural and recreational lives of Chinese audiences, with American and Korean film and television dramas being the core content types they consume. The viewing frequency shows a pattern of being high in the middle and low at both ends. However, contemporary Chinese audiences have developed a rational and multi-layered cognition of the cultural influences of foreign film and television dramas. They clearly perceive the Western values exported behind Hollywood's production techniques, and at the same time, they recognize that the influence of Korean dramas remains superficial and has not exerted a profound impact on their core cognition. In terms of local cultural identity, although audiences have concerns about the potential challenges posed by foreign film and television dramas, their attitudes are not extreme. They do not simply equate the dissemination of foreign film and television dramas with cultural hegemony; instead, they generally believe that their influences are basically balanced in both positive and negative aspects, demonstrating an objective and comprehensive perspective.

Audiences have put forward core demands for the development of domestic film and television dramas: strengthening internal capabilities and maintaining openness and inclusiveness. They expect domestic film and television dramas to focus on upgrading production standards, tell Chinese stories more effectively, enhance cultural confidence and export local values. Meanwhile, they hope domestic works can rationally learn from advanced experience through benign competition with foreign film and television dramas, rather than rejecting them blindly. This reflects that driven by the cultural revitalization policies, contemporary Chinese audiences are both full of confidence in local culture and hold an inclusive attitude toward foreign cultures. They have

developed a rational cultural cognition amid the integration of diverse cultures. Based on such an audience foundation, the cultural dissemination of foreign film and television dramas has not brought about a severe hegemonic effect on Chinese audiences, which provides new ideas for the balanced development of diversified film and television culture in the future.

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Philological Sciences

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SHI'ISM IN THE SYSTEM OF ISLAMIC PHILOSOPHY

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Abstract

This article examines Shi'ism as an independent philosophical system within the structure of the Islamic intellectual tradition. It analyzes the key concepts of Shi'ite thought, including the Imamate, esoteric hermeneutics (*ta'wīl*), the specific features of Shi'ite *kalām*, as well as the development of metaphysics within the framework of Illuminationism (*Ishrāqism*) and the Transcendent Theosophy of Mullā Ṣadrā. Special attention is given to the philosophy of Shi'ism in Azerbaijan and contemporary Iran. It is demonstrated that Shi'ism constitutes an integral philosophical system in which rational thought, revelation, and mystical experience are brought into unity. The article concludes by emphasizing the significance of Shi'ite philosophy for contemporary philosophy of religion and intercultural dialogue.

Keywords: Shi'ism, Islamic philosophy, Imamate, *ta'wīl*, Mullā Ṣadrā, Illuminationism, philosophy of Iran, philosophy of Azerbaijan, metaphysics, *kalām*.

Introduction

Shi'ism represents one of the most profound and conceptually developed traditions in the intellectual history of Islam. Its significance extends far beyond confessional affiliation, as it constitutes a comprehensive philosophical system in which religious revelation, metaphysics, hermeneutics, and the philosophy of history are integrated into an organic unity. Unlike many other currents of Islamic thought, Shi'ism is not confined to the dogmatic exposition of doctrine but aspires to a philosophical comprehension of the very nature of revelation, the structure of knowledge, and the place of the human being within the cosmic and historical order.

The formation of the Shi'ite tradition is rooted in the early stages of Islamic history, when the question of the legitimacy of authority and spiritual leadership became central to the Muslim community. However, already at the initial stages of its development, Shi'ism transcended the boundaries of a purely politico-religious discourse and began to form its own intellectual paradigm. Within this paradigm, such categories as the Imamate, hidden knowledge, the inner meaning of revelation, and the historical mission of humanity acquire fundamental importance. In this way, Shi'ism from its very inception demonstrates a tendency toward the philosophical interpretation of religious experience.

For a long time, Western Orientalist scholarship tended to interpret Shi'ism primarily as a politico-religious movement that emerged from disputes over succession following the death of the Prophet Muhammad. This approach, characteristic of the classical historical-critical school of the nineteenth and early twentieth centuries, reduced the Shi'ite tradition to the problem of political legitimacy and largely neglected its philosophical content. However, in the second half of the

twentieth century, this perspective underwent a significant revision, largely due to more profound studies in Islamic philosophy and religious hermeneutics.

A decisive role in this reassessment was played by the works of Henry Corbin, who was the first to demonstrate systematically that Shi'ite thought possesses its own metaphysics and philosophy of the symbol. He emphasized that the Shi'ite tradition represents "one of the richest and most profound spiritual and philosophical traditions in Islam" [Corbin H. *History of Islamic Philosophy*. London: Kegan Paul International, 1993. P. 12]. According to Corbin, it is precisely within Shi'ism that the living connection between revelation and philosophy is preserved, since particular importance is accorded to the inner, esoteric interpretation of sacred texts.

Seyyed Hossein Nasr, developing this line of thought, argues that Islamic philosophy in its authentic form cannot be reduced to a purely rationalistic tradition and must instead be understood as a synthesis of reason and spiritual experience. In this context, Shi'ite philosophy emerges as the most consistent expression of this synthetic orientation. Nasr notes that Islamic philosophy "cannot be adequately understood without taking into account its spiritual dimension" and that it is precisely the Shi'ite tradition that ensures the preservation of this dimension [Nasr S. H. *Islamic Philosophy from Its Origin to the Present*. Albany: SUNY Press, 2006. Pp. 45–47].

Contemporary scholarship likewise confirms that Shi'ism should be regarded not merely as a religious denomination but as a complex intellectual system encompassing metaphysics, philosophy of history, epistemology, and political philosophy. Within this system, original concepts are developed, such as the Imamate as a metaphysical principle, *ta'wil* as a method of interpreting revelation, and a distinctive understanding of the historical process as oriented toward the realization of divine justice.

Thus, Shi'ism should not be treated as a peripheral phenomenon in the history of Islamic thought, but rather as one of its central philosophical traditions. Its study not only deepens our understanding of the internal structure of Islamic philosophy but also brings to light universal philosophical problems concerning the relationship between reason and faith, knowledge and revelation, history and metaphysics. In this sense, Shi'ism constitutes an important object of philosophical inquiry, possessing significant potential for contemporary intercultural and intercivilizational dialogue.

Shi'ism as a Distinct Form of Islamic Philosophy

Shi'ism represents a unique mode of philosophical thinking within the Islamic intellectual tradition, in which rational cognition is not opposed to revelation but is integrated into the process of its interpretation and deepening. Unlike Peripatetic philosophy (*falsafa*), which is primarily oriented toward a demonstrative and logical model of knowledge and derives a substantial part of its conceptual apparatus from the Greek philosophical tradition, as well as unlike classical *kalām*, which is largely concerned with apologetics and the defense of doctrinal tenets, Shi'ite thought is from the outset directed toward a synthesis of different forms of knowledge—rational, symbolic, and mystical.

This synthetic orientation is manifested in the fact that, in Shi'ism, philosophy is not separated from religious experience and is not regarded as an autonomous domain of theoretical inquiry. On the contrary, it is understood as an organic component of spiritual life, aimed at the attainment of truth through the inner transformation of the subject. In this sense, philosophy acquires an existential dimension: it becomes not merely a system of concepts and arguments, but also a form of spiritual practice that presupposes the participation of the knower in the very process of the disclosure of truth.

Such an understanding of philosophy is grounded in a fundamental conviction of the Shi'ite tradition, namely that truth cannot be exhausted by its rational expression. Rational thinking is regarded as a necessary but insufficient instrument of knowledge. It must be complemented by

symbolic and intuitive modes of perception that enable access to the deeper levels of reality. For this reason, hermeneutics—aimed at uncovering the inner meaning of revelation—as well as mystical experience, understood as a form of immediate knowledge, acquire particular importance in Shi'ite philosophy.

Seyyed Hossein Nasr emphasizes that authentic Islamic philosophy is always connected with “the inner dimension of revelation and spiritual experience” [Nasr S. H. *Islamic Philosophy from Its Origin to the Present*. Albany: SUNY Press, 2006. P. 67]. This principle finds its most complete realization precisely in Shi'ism, where philosophy, theology, and mysticism not only coexist but form a unified intellectual system. Within this system, philosophical knowledge is not opposed to faith; rather, it functions as its deepening and its rational-symbolic articulation.

Another distinctive feature of Shi'ite philosophy is its orientation toward personalized knowledge, linked to the figure of the Imam as the bearer of truth. This distinguishes it from abstract philosophical systems in which knowledge is conceived as universal and impersonal. In Shi'ism, knowledge possesses a personal dimension insofar as it is transmitted through a spiritual lineage and is bound to the authority of the bearer of sacred knowledge.

Furthermore, Shi'ite philosophy is characterized by a specific understanding of time and history. In contrast to linear models of historical development, it interprets history as a process of the unfolding of hidden meaning, in which past, present, and future are interconnected through the idea of spiritual guidance. This provides Shi'ite philosophy with an additional dimension that links metaphysics with the philosophy of history.

Thus, Shi'ism may be defined as a form of integral philosophy in which knowledge is understood as a process of the disclosure of truth through the interaction of reason, revelation, and spiritual experience. This integration of different modes of cognition renders Shi'ite philosophy one of the most complex and profound traditions of Islamic thought, capable of offering original solutions to fundamental philosophical problems concerning the nature of truth, knowledge, and human existence.

The Imamate as the Central Principle of Shi'ite Philosophical Worldview

The central category of Shi'ite philosophy is the concept of the Imamate, which determines not only the structure of the religious community but also the fundamental principles of knowledge, being, and the historical process. In the Shi'ite tradition, the Imam is not regarded as a political leader or merely an administrative head of the community, but as the bearer of divine knowledge and a mediator between the transcendent and human worlds. This confers upon the Imamate a fundamentally different status in comparison with institutions of authority in other religious and philosophical systems: it becomes not merely a social institution, but an ontological and metaphysical principle.

The philosophical significance of the Imamate is revealed прежде всего through its connection with the idea of the continuity of divine guidance. In Shi'ite thought, revelation is not understood as a completed act limited to the historical epoch of prophecy, but rather as a process that continues through the figure of the Imam. In this sense, the Imamate functions as the preservation and actualization of divine knowledge within history.

Muhammad Husayn Tabataba'i emphasizes that “The Imam is the necessary guide of humanity” [Tabataba'i M. H. *Shi'ite Islam*. Albany: SUNY Press, 1975. P. 186], thereby affirming that the Imamate is not a historically contingent institution but an ontological necessity. This assertion implies that human society cannot, in principle, exist without spiritual guidance, since the knowledge of truth is not self-evident and requires a special form of mediation. In this context, the Imam appears as the guarantor of truth and the source of its proper understanding.

Developing this perspective, Mohammad Ali Amir-Moezzi notes that “the Imam is the locus of divine knowledge” [Amir-Moezzi M. A. *The Divine Guide in Early Shi'ism*. Albany: SUNY Press, 1994.

P. 45], that is, the Imam represents the very site of the presence of divine knowledge in the world. This statement carries profound philosophical implications, as it suggests that knowledge does not exist in abstraction but is embodied in a concrete person endowed with a particular spiritual status. In this way, knowledge in Shi'ite philosophy acquires a personalist character, distinguishing it from many other philosophical traditions that tend toward the universalization and depersonalization of truth.

The Imamate also performs an epistemological function, as it determines the conditions for the possibility of true knowledge. In the Shi'ite tradition, it is maintained that rational thinking alone is incapable of providing access to the fullness of truth, since it is limited by human nature and prone to error. The Imam, endowed with special knowledge, reveals the inner meaning of revelation and thereby makes genuine understanding possible. In this sense, the Imamate serves as a principle that overcomes the gap between divine and human knowledge.

Equally important is the hermeneutical function of the Imamate. Since revelation possesses a multilayered structure, encompassing both external and internal meanings, there arises a need for authoritative interpretation. The Imam functions as the bearer of this interpretive authority, granting access to the hidden levels of meaning. Thus, the Imamate becomes a key element of Shi'ite hermeneutics, linking the text of revelation with its spiritual content.

Moreover, the Imamate possesses a pronounced ontological dimension. In a number of Shi'ite philosophical and theological doctrines, the Imam is conceived as a cosmic principle that ensures the order and harmony of the world. In this context, he appears not only as a historical figure but also as an element of the very structure of being. Such an understanding brings Shi'ite philosophy closer to metaphysical systems in which mediation between the Absolute and the world plays a central role.

The Imamate is also closely connected with the philosophy of history. In the Shi'ite tradition, history is understood as a process directed toward the unfolding of truth and the restoration of justice, and the Imam plays a central role in this process. Even in the condition of the "hidden Imam," his presence is maintained as a metaphysical reality that determines the meaning of historical movement. This imparts a teleological character to history and connects it with the divine plan.

Thus, the concept of the Imamate constitutes a fundamental principle of Shi'ite philosophy, integrating ontological, epistemological, hermeneutical, and historical dimensions. Through this category, Shi'ism constructs a holistic worldview in which knowledge, being, and history are intrinsically interconnected. For this reason, the Imamate should be regarded not merely as a religious doctrine, but as a key philosophical category that defines the specificity of the Shi'ite intellectual tradition.

Esoteric Hermeneutics and the Nature of Knowledge

One of the defining features of Shi'ite philosophy is its developed theory of the interpretation of revelation, based on the fundamental distinction between the external (*zāhir*) and internal (*bāṭin*) meanings. This distinction is not merely textual or philological, but possesses a deep ontological and epistemological significance. In the Shi'ite tradition, revelation is understood as a multilayered reality in which the literal meaning of the text represents only an initial level that conceals deeper symbolic and metaphysical meanings.

This understanding of the text is connected with a broader philosophical assumption according to which reality itself has a hierarchical structure. The world is not reducible to its outward manifestation, but includes inner levels of meaning that require specific modes of cognition. In this context, hermeneutics becomes not simply a method of interpretation, but a means of ontological disclosure of reality.

The central concept of Shi'ite hermeneutics is *ta'wīl*, an interpretation aimed at returning the text to its original meaning. Henry Corbin defines *ta'wīl* as a "return to the original meaning, to the archetype" [Corbin H. *History of Islamic Philosophy*. London: Kegan Paul International, 1993. P. 13]. This definition underscores that interpretation in the Shi'ite tradition is not arbitrary, but oriented toward the recovery of a deeper reality concealed behind the external form of the text. In this sense, *ta'wīl* represents not only an intellectual operation but also a spiritual movement—from the outward to the inward, from the manifest to the hidden. It presupposes that the text of revelation possesses a transcendent dimension that cannot be fully expressed in its literal form. Consequently, the task of interpretation is not to create new meaning, but to uncover an already existing, though concealed, content.

Muhammad Husayn Tabataba'i notes that "the Qur'an possesses an inner meaning which cannot be grasped by ordinary reasoning alone" [Tabatabai M. H. *Shi'ite Islam*. Albany: SUNY Press, 1975. P. 39]. This statement is of fundamental importance for understanding the nature of knowledge in Shi'ite philosophy. It implies that rational thought, while necessary, is not sufficient for attaining truth. Genuine knowledge requires transcending discursive reasoning and turning toward deeper forms of cognition, including intuition and spiritual experience.

In this connection, a special role is assigned to the figure of the Imam as the bearer of true knowledge and the interpreter of revelation. Since the inner meaning of the text is not directly accessible to everyone, there arises the necessity of an authoritative mediator capable of disclosing it. The Imam functions as the guarantor of correct interpretation, linking the text of revelation with its metaphysical content. Thus, hermeneutics in Shi'ism is inseparable from the concept of the Imamate.

Shi'ite hermeneutics also presupposes that knowledge has a dynamic character. The understanding of the text is not fixed once and for all, but develops in accordance with the spiritual growth of the subject. This implies that interpretation depends not only on the text itself but also on the state of the interpreter: the deeper the spiritual experience, the more profound the level of meaning that becomes accessible.

Furthermore, the distinction between *zāhir* and *bāṭin* reflects a broader philosophical idea concerning the dual structure of reality. The external world is perceived as a symbol pointing to a hidden inner reality. Thus, hermeneutics becomes a universal method of cognition applicable not only to texts but also to the world as such.

Within this framework, knowledge in Shi'ite philosophy acquires a multilayered structure, encompassing sensory perception, rational thought, symbolic understanding, and mystical contemplation. These levels do not exclude one another but rather complement each other, forming an integrated system of cognition.

Thus, esoteric hermeneutics in Shi'ism constitutes not merely a method of interpreting religious texts, but a fundamental philosophical principle that determines both the nature of knowledge and the structure of reality. It enables the overcoming of the limitations of purely rational approaches and opens the possibility of a deeper comprehension of truth based on the unity of reason, revelation, and spiritual experience.

Shi'ism and the Development of Islamic Metaphysics

Shi'ite philosophy exerted a decisive influence on the development of Islamic metaphysics, above all within the framework of the Iranian intellectual tradition, where it became the foundation for the formation of the most mature and synthetic philosophical systems of the Islamic world. Unlike the earlier stages of the development of Islamic philosophy, in which borrowings from ancient Greek thought predominated, Shi'ite philosophy elaborated its own metaphysical paradigm, within which rational, theological, and mystical elements were united into a single conceptual structure.

Farhad Daftary rightly notes that Shi'ite thought "played a major role in shaping Islamic intellectual history" [Daftary F. *A History of Shi'i Islam*. London: I.B. Tauris, 2013. P. 120], thereby underscoring its fundamental significance for the development of philosophy in the Islamic world. This influence is manifested not only in particular concepts, but also in the formation of a distinctive type of metaphysical thinking oriented toward the synthesis of different sources of knowledge.

Within the Shi'ite tradition, the dualism between philosophy and theology that was characteristic of the early development of Islamic intellectual life is gradually overcome. If Peripatetic philosophy (*falsafa*) sought the autonomy of reason and was grounded in a demonstrative and logical model of cognition, while *kalām* developed as a discipline aimed at defending the dogmas of faith, Shi'ite philosophy seeks their integration. As a result, a new metaphysical perspective emerges, in which rational thinking, revelation, and mystical experience are regarded as mutually complementary forms of knowledge.

Of particular importance in this process is the interaction of three intellectual traditions: Peripatetic philosophy, Sufi mysticism, and Shi'ite theology. Peripatetic philosophy, deriving from Ibn Sīnā, provided Shi'ite thought with a developed conceptual apparatus, including the categories of essence and existence, causality, necessity, and possibility. Sufism, in turn, contributed the experience of immediate spiritual knowledge, emphasizing the inward and intuitive perception of truth. Shi'ite theology supplied the normative and hermeneutical foundation, linking philosophical ideas with revelation and the concept of the Imamate.

The synthesis of these three components led to the formation of a distinctive metaphysical model in which being is understood as a hierarchically ordered reality, and knowledge as a process of gradual ascent from the outward to the inward. In this model, metaphysics ceases to be a purely abstract discipline and acquires an existential dimension, since the knowledge of truth is bound up with the inner transformation of the subject.

This synthesis becomes especially evident in the philosophical schools that took shape in Iran during the Safavid era and in the period that followed. Within the School of Isfahan, philosophy, theology, and mysticism were united into a single system that became the basis for the further development of Islamic metaphysics. Here philosophy is no longer opposed to religion, but is regarded as its deepened understanding.

An important feature of Shi'ite metaphysics is also its orientation toward personalized knowledge connected with the figure of the Imam. Unlike abstract philosophical systems in which truth is conceived as universal and impersonal, the Shi'ite tradition emphasizes that knowledge has a concrete bearer and is transmitted through spiritual succession. This confers upon metaphysics a distinctive character, joining ontology with epistemology and anthropology.

Moreover, Shi'ite metaphysics is characterized by a dynamic understanding of being. Unlike static models in which the world is regarded as a completed structure, here being is understood as a process in constant becoming. This makes it possible to account for change and development in the world without disrupting its ontological unity.

It should also be noted that in Shi'ite philosophy metaphysics is closely connected with hermeneutics. The understanding of being and the understanding of the text of revelation prove to be interrelated processes, since both presuppose a movement from the external to the internal. This makes metaphysics not only a theoretical but also an interpretive discipline.

Thus, Shi'ite philosophy not only develops Islamic metaphysics but also transforms it by creating a new intellectual paradigm. Within this paradigm, philosophy, theology, and mysticism are united into a single system in which knowledge is understood as a process of the disclosure of truth, and being as a dynamic hierarchy of meanings. It is precisely owing to this synthesis that Shi'ite metaphysics becomes one of the most developed and conceptually rich traditions in the history of world philosophy.

Illuminationism and the Philosophy of Mullā Ṣadrā

The philosophy of Illuminationism (*Ishrāqism*), developed by Shihāb al-Dīn al-Suhrawardī, represents one of the key turning points in the development of Islamic metaphysics, marking the transition from a predominantly rationalistic model of cognition to an intuitive and mystical apprehension of truth. Unlike Peripatetic philosophy, which is oriented toward demonstrative reasoning and categorical analysis, Illuminationism places at the center of the philosophical process immediate spiritual illumination (*ishrāq*), understood as an inward act of grasping reality. The central category of Suhrawardī's philosophy is light, which is interpreted not as a physical phenomenon but as the universal principle of being and knowledge. In his system, light functions as the primary reality from which the entire hierarchy of existence proceeds. All levels of being are interpreted as degrees of the intensity of light—from pure, absolute light to its weakened manifestations in the material world.

Henry Corbin, in his analysis of Suhrawardī's philosophy, emphasizes its metaphysical significance, noting that "Suhrawardi revived the ancient wisdom of Light" [Corbin H. *History of Islamic Philosophy*. London: Kegan Paul International, 1993. P. 205]. This "revival" is connected not only with a turn toward ancient Iranian and Neoplatonic traditions, but also with the attempt to create a new philosophical system in which knowledge is understood as the inward illumination of consciousness.

Within Illuminationism, a radical rethinking of the nature of knowledge takes place. If in the Peripatetic tradition knowledge is understood as a correspondence between intellect and object, in Suhrawardī it acquires the character of presence: the knower does not merely reflect the object but enters into an immediate ontological relation with it. This means that knowledge becomes a form of participation in being, rather than merely its description.

It was precisely this orientation toward immediate knowledge and spiritual experience that exerted a decisive influence on the subsequent development of Shi'ite philosophy, preparing the ground for the emergence of the most mature metaphysical system in the Islamic world—the philosophy of Mullā Ṣadrā.

Mullā Ṣadrā (Ṣadr al-Dīn Shīrāzī) effects a synthesis of Peripatetic philosophy, Illuminationism, and Shi'ite theology, thereby creating his celebrated "Transcendent Theosophy" (*al-ḥikma al-muta'aliyya*). In his system, a qualitatively new level of philosophical thought is achieved, in which rational analysis, mystical experience, and revelation are united into a single ontological and epistemological structure.

The central principle of Mullā Ṣadrā's philosophy is the idea of the primacy of existence (*aṣālat al-wujūd*). In contrast to the classical Aristotelian and Avicennian tradition, in which essence (*māhiyya*) is treated as the basis of things, Ṣadrā maintains that it is existence (*wujūd*) that constitutes true reality, whereas essences are merely abstractions generated in thought. This position radically transforms the structure of metaphysics by shifting the emphasis from logical determinations to ontological reality.

A major consequence of this principle is the doctrine of the gradation of being (*tashkīk al-wujūd*), according to which existence is not homogeneous but possesses different degrees of intensity. All levels of reality—from the material world to divine being—represent different modes of one and the same existence. This enables Mullā Ṣadrā to overcome the dualism between God and the world while preserving the distinction between them.

No less significant is the theory of substantial motion (*al-ḥaraka al-jawhariyya*), according to which change affects not only the accidents (the external properties of things) but their very substance. This means that being is in a constant process of becoming and inward transformation. In Ṣadrā's philosophy, the world is not a static structure but a dynamic reality existing in ceaseless motion. Mullā Ṣadrā's epistemology likewise undergoes a profound transformation. He introduces a distinction between acquired or representational knowledge (*'ilm al-ḥuṣūlī*) and knowledge by

presence (*'ilm al-ḥuḍūrī*). The latter is understood as the immediate experience of the object, unmediated by concepts. It is precisely this mode of knowledge that constitutes the highest form of cognition, since it eliminates the gap between subject and object.

Ibrahim Kalin emphasizes that in Mullā Ṣadrā's philosophy "true knowledge is based on presence and direct witnessing" [Kalin I. *Knowledge in Later Islamic Philosophy*. Oxford: Oxford University Press, 2010. P. 89], thereby indicating the fundamental role of intuitive cognition.

Seyyed Hossein Nasr, assessing the significance of Ṣadrā, notes that his philosophy represents "the culmination of Islamic philosophical tradition" [Nasr S. H. *Islamic Philosophy from Its Origin to the Present*. Albany: SUNY Press, 2006. P. 278]. This means that in his system the highest degree of synthesis of the major currents of Islamic thought is attained.

Another distinctive feature of Mullā Ṣadrā's philosophy is its close connection with Shi'ite theology. The concept of the Imamate, the idea of inward knowledge, and the hermeneutical approach to revelation all receive metaphysical grounding within his system. In this way, philosophy ceases to be an autonomous discipline and becomes part of a broader spiritual tradition.

The synthesis of Illuminationism and Mullā Ṣadrā's philosophy leads to the formation of a distinctive type of metaphysics in which being is understood as light, knowledge as presence, and philosophy as a path of spiritual ascent. Within this metaphysics, the opposition between reason and intuition, theory and practice, philosophy and religion disappears.

Thus, Illuminationism and the philosophy of Mullā Ṣadrā constitute the core of Shi'ite metaphysics, determining its basic principles and directions of development. They represent the highest point in the evolution of Islamic philosophy, in which the synthesis of rational thought, mystical experience, and revelation is achieved, making it possible to regard Shi'ite philosophy as one of the deepest and most integral metaphysical systems in the history of world thought.

Shi'ite Kalām and the Specificity of Rationality

Shi'ite *kalām* represents a distinctive form of rational theology that differs substantially both from classical Sunni *kalām* and from Peripatetic philosophy. Its specificity lies in the fact that rationality within it does not function as an autonomous and self-sufficient sphere of thought; rather, it is from the outset integrated into a broader spiritual-philosophical system encompassing revelation, tradition, and mystical experience.

In the classical Islamic intellectual tradition, *kalām* developed primarily as a polemical discipline aimed at defending the dogmatic tenets of faith through the use of logical arguments. In the Shi'ite context, however, *kalām* acquires a different content and function. It ceases to be merely an apologetic practice and becomes part of an integral philosophical system in which rational thought is directed not only toward the defense of faith, but also toward its deeper comprehension.

Murtaza Mutahhari emphasizes that Shi'ite *kalām* "is connected both with hadith and philosophy" [Mutahhari M. *An Introduction to Islamic Theology*. Tehran: Sadra, n.d. P. 15]. This statement is of fundamental importance, since it points to the dual nature of Shi'ite rationality. On the one hand, it is rooted in religious tradition and relies on the authority of the *hadith* and of the Imams; on the other hand, it actively employs philosophical methods and categories derived from the broader intellectual tradition.

This conjunction gives rise to a particular type of rationality that may be characterized as interpretive and contextual. Unlike abstract rationalism, which aspires to universal and ahistorical truths, Shi'ite rationality is always linked to a concrete spiritual tradition and directed toward the disclosure of the meaning of revelation. It does not oppose reason to faith; rather, it regards reason as an instrument necessary for the correct understanding of faith.

In this context, it is important that Shi'ite *kalām* is closely connected with the concept of the Imamate. Since the Imam is regarded as the bearer of true knowledge, rational thought cannot be

wholly separated from the authority of spiritual guidance. This means that truth is not the result of exclusively individual reasoning, but is disclosed within a particular tradition and through the mediation of its bearers.

Thus, rationality in Shi'ite philosophy acquires a personalized character. It is not reducible to universal logical operations, but includes an element of spiritual authority and succession. This distinguishes it from the Western philosophical tradition, in which rationality is often understood as an autonomous capacity of the subject.

Moreover, Shi'ite *kalām* is characterized by its openness to philosophical synthesis. Unlike certain forms of Sunni *kalām*, which in certain historical periods distanced themselves from philosophy, the Shi'ite tradition, by contrast, actively interacted with philosophical schools, including Peripateticism and Illuminationism. This interaction contributed to the deepening of metaphysical inquiry and to the expansion of the horizons of rational thought.

It should also be noted that rationality in Shi'ite *kalām* is not limited to discursive thought. It includes elements of intuitive and symbolic cognition, which brings it closer to the mystical tradition. This means that reason in Shi'ite philosophy is understood not only as a logical instrument, but also as a faculty capable of perceiving deeper levels of reality.

Thus, Shi'ite *kalām* represents a unique form of rational theology in which reason, revelation, and spiritual experience form a unified system. Rationality within this system is not autonomous, but rooted in spiritual tradition and directed toward the disclosure of the inner meaning of truth. This makes Shi'ite philosophy one of the most complex and integrative forms of religious thought, capable of overcoming the opposition between faith and reason.

Philosophy of History and Messianism

Shi'ite philosophy of history represents one of the most original and conceptually developed models of historical consciousness in Islamic thought. Unlike secular or purely empirical approaches, which regard history as a collection of accidental events or as the result of social and political forces, the Shi'ite tradition interprets the historical process as an internally meaningful and directed movement possessing a metaphysical foundation and a teleological structure. In this context, history is understood not as a neutral succession of facts, but as the space in which the divine design is realized, truth is disclosed, and justice is restored.

A key element of Shi'ite philosophy of history is the idea of divine guidance (*hidāya*), which is exercised through the chain of prophets and Imams. Unlike conceptions that regard revelation as a completed event, characteristic of certain other interpretations of Islam, Shi'ite thought maintains that divine guidance continues to operate in history through the institution of the Imamate. This gives the historical process a continuous character and links it with the metaphysical dimension.

Farhad Daftary observes that the Shi'ite tradition forms "a distinct historical consciousness" [Daftary F. *A History of Shi'i Islam*. London: I.B. Tauris, 2013. P. 150], thereby underscoring that Shi'ism offers a particular model for the understanding of time and history. This model differs from linear historicism in that past, present, and future are united through the idea of spiritual succession and the expectation of the final disclosure of truth.

Of special significance in Shi'ite philosophy of history is the messianic idea associated with the expectation of the Hidden Imam (*al-Mahdī*). According to Shi'ite doctrine, the Twelfth Imam did not disappear definitively, but remains in a state of occultation (*ghayba*), continuing to exert spiritual influence upon the world. This doctrine lends history a particular tension, since it is perceived as a process of expectation and preparation for the ultimate triumph of justice.

Messianism in Shi'ism is not reducible to passive expectation of a future event; rather, it has an active philosophical and ethical meaning. It shapes a specific relation to time in which the present is understood as a space of responsibility and action. Human historical existence acquires a

teleological orientation, since each action is related to the ultimate goal—the restoration of a just order.

In this context, history is understood as a dramatic process in which truth and falsehood, justice and injustice, are in conflict. A special place within this process is occupied by the event of Karbala, which in the Shi'ite tradition acquires symbolic and philosophical significance. The sacrifice of Imam Husayn is interpreted not only as a historical fact, but as an eternal archetype of resistance to evil and affirmation of truth. In this way, history acquires not only a linear but also a symbolic dimension.

Shi'ite philosophy of history also presupposes that the historical process possesses an inner structure connected with the disclosure of hidden meaning. This brings it close to the hermeneutical approach, in which history is regarded as a text requiring interpretation. Just as revelation possesses an external and an internal meaning, history too has a hidden dimension accessible only through philosophical and spiritual understanding.

Moreover, the messianic perspective makes it possible to overcome a pessimistic view of history. Despite the presence of evil and injustice, history in Shi'ite philosophy is neither chaotic nor devoid of meaning. On the contrary, it is directed toward a definite goal guaranteed by the divine plan. This lends historical consciousness stability and hope, while at the same time stimulating active human participation in the transformation of the world.

Thus, Shi'ite philosophy of history constitutes a complex system in which metaphysics, theology, and ethics are united into a single conception. History is understood as a process of the disclosure of truth directed toward the restoration of justice, while messianism functions as the key principle determining its meaning and structure. Herein lies one of the most significant features of Shi'ite philosophy, distinguishing it from other models of historical thought and giving it its profound philosophical character.

The Philosophy of Shi'ism in Azerbaijan

The philosophy of Shi'ism in Azerbaijan constitutes an important and distinctive branch of the Islamic intellectual tradition, formed at the intersection of Islamic theology, Sufi mysticism, and Eastern philosophy. Azerbaijan's geographical position as a cultural and civilizational crossroads between Iran, the Arab world, and the Turkic regions created favorable conditions for the intensive interaction of diverse intellectual traditions, which in turn determined the particularly synthetic orientation of philosophical thought in the region.

The historical development of Shi'ite philosophy in Azerbaijan is closely connected with the processes of Islamization and the subsequent institutionalization of Shi'ism, especially during the Safavid period (sixteenth–seventeenth centuries), when Shi'ism was proclaimed the state religion. This event had not only political but also profound cultural and philosophical significance, since it contributed to the formation of a stable Shi'ite intellectual environment that included religious schools, philosophical circles, and literary traditions.

A distinctive feature of the philosophy of Shi'ism in Azerbaijan is its pronounced connection with poetic and artistic forms of thought. Unlike the strictly systematic philosophical treatises characteristic of classical Islamic philosophy, many philosophical ideas here found expression in poetry, symbolism, and allegory. This is related to the influence of the Sufi tradition, in which poetic language functions as a means of conveying inward and esoteric knowledge.

A significant contribution to the development of this tradition was made by such thinkers and poets as Imadaddin Nasimi, Shah Isma'il Khata'i, and Muhammad Fuzuli. In their works, philosophical and religious ideas assume the form of symbolic expression in which anthropology, metaphysics, and ethics are interwoven. Thus, in the poetry of Nasimi the idea of the divine nature of the human being is manifested, connected with the Sufi doctrine of the unity of being, whereas

the творчество of Fuzuli reflects a profound meditation on love as a metaphysical principle uniting the human being and the Absolute.

As Zakir Mamedov observes, “the philosophical thought of Azerbaijan developed as a synthesis of different traditions” [Mamedov, Z. *History of Philosophy in Azerbaijan*. Baku: Elm, 1994. P. 112]. This statement makes it possible to regard Azerbaijani Shi’ite philosophy as the result of the interaction of several intellectual lines: rational philosophy, mystical experience, and religious teaching.

Another important feature of this tradition is its orientation toward the inward and spiritual dimension of religion. The influence of Shi’ite hermeneutics, based on the distinction between external and internal meaning, contributed to the formation of a philosophy in which the central place is occupied by the problem of hidden knowledge and its disclosure through symbol and interpretation.

It should also be noted that the philosophy of Shi’ism in Azerbaijan is not confined to the classical period, but continues to develop in later eras, including the present. Contemporary scholarship emphasizes that this tradition retains its relevance, functioning as an important element of the cultural identity and intellectual heritage of the region (see: Abasov, A. S. *The Philosophical Doctrine of Shi’ism*. Baku, 2024. Manuscript).

Thus, the philosophy of Shi’ism in Azerbaijan represents a unique example of the synthesis of different intellectual and cultural traditions in which philosophy, religion, and poetry form a single system. It demonstrates that Shi’ite thought is capable of adapting to different cultural contexts while preserving its inner coherence and philosophical depth.

The Philosophy of Shi’ism in Contemporary Iran

In contemporary Iran, Shi’ite philosophy continues to develop actively, demonstrating a unique capacity to unite tradition and modernity within a single intellectual and spiritual paradigm. Unlike many other cultural contexts, where modernization led to a rupture with religious philosophy, in Iran the opposite tendency may be observed: classical Shi’ite thought not only retains its significance but also serves as a foundation for the interpretation of contemporary social, political, and cultural processes.

One of the key factors determining the present state of Shi’ite philosophy is its institutionalization after the Islamic Revolution of 1979. The Revolution was not merely a political event, but also a philosophical turning point, demonstrating the possibility of embodying religious-philosophical ideas within the structure of the state. In this context, special importance attaches to the concept of *wilāyat al-faqīh* (the governance of the Islamic jurist), developed by Ruhollah Khomeini.

This concept constitutes a reinterpretation of the classical doctrine of the Imamate under the conditions of the absence of the manifest Imam. Whereas in traditional Shi’ite doctrine the Imam appears as the bearer of divine knowledge and supreme authority, under the conditions of occultation (*ghayba*) there arises the need for a substitutive institution. *Wilāyat al-faqīh* performs this function by asserting that the religious scholar (*faqīh*), endowed with knowledge and moral authority, may exercise guidance over society. In this way, the philosophical idea of the Imamate receives a new historical embodiment, joining a metaphysical principle with political practice.

The significance of Shi’ite philosophy in contemporary Iran, however, is not limited to political theology. It continues to develop within both academic and spiritual life, where a special place is occupied by renewed engagement with classical philosophical systems, above all with the thought of Mullā Ṣadrā. His philosophy remains a central component of instruction in religious seminaries (*ḥawzas*) and universities and continues to be the object of active interpretation and rethinking.

Seyyed Hossein Nasr notes that the philosophical tradition of Iran preserves continuity and “continues to develop in the modern context” [Nasr S. H. *Islamic Philosophy from Its Origin to the Present*. Albany: SUNY Press, 2006. P. 310]. This development is manifested in attempts to adapt

classical concepts to modern conditions, including questions of science, technology, globalization, and cultural identity.

Contemporary Shi'ite philosophy also actively engages with the Western philosophical tradition. In Iran, debates continue concerning the relation between reason and faith, science and religion, individual freedom and social responsibility. These discussions demonstrate that Shi'ite philosophy is not a closed system, but one capable of dialogue with other intellectual traditions.

Of special significance in the contemporary Iranian context is the problem of spirituality. Under conditions of globalization and cultural transformation, Shi'ite philosophy functions as a source of stable spiritual identity, offering a model of the human being in which rationality, faith, and inner experience exist in harmony. In contrast to secular models oriented toward the autonomy of the subject, the Shi'ite tradition emphasizes the necessity of a connection between the human being and a transcendent source of meaning.

At the same time, contemporary spirituality in Iran is not reducible to traditional forms of religiosity, but includes elements of philosophical reflection and personal quest. Here one may observe the influence both of the Sufi tradition and of Mullā Ṣadrā's philosophy, in which knowledge is understood as the inward experience of being. Spirituality thus acquires not only a religious but also a philosophical character.

An important aspect of contemporary Shi'ite philosophy is also its ethical dimension. In the face of social and political challenges, it seeks to formulate principles of justice, responsibility, and human dignity, drawing upon classical teaching while adapting it to contemporary conditions.

Thus, the philosophy of Shi'ism in contemporary Iran represents a dynamic and multilayered system in which tradition and modernity are in constant dialogue. It demonstrates the capacity of religious philosophy not only to preserve its heritage, but also to participate actively in the formation of the contemporary intellectual and spiritual space. It is precisely in this union of continuity and renewal that its particular significance lies, both for the Islamic world and for world philosophy as a whole.

Conclusion

The foregoing analysis makes it possible to regard Shi'ism not merely as one of the branches of Islam, but as a coherent and internally integrated philosophical system in which metaphysics, theology, hermeneutics, and the philosophy of history form an organic unity. In contrast to reductionist approaches that reduce Shi'ism to a politico-religious movement, it should be understood as a complex intellectual tradition possessing its own conceptual apparatus, methodology, and historical dynamics.

The central principle of this system is the Imamate, which determines not only the structure of the religious community but also the fundamental foundations of knowledge and being. Through the concept of the Imamate, Shi'ite philosophy affirms the possibility of the continuous presence of truth in history and thereby overcomes the gap between the transcendent and human dimensions.

A developed esoteric hermeneutics, grounded in the distinction between the external and internal meanings of revelation, lends Shi'ite thought a special depth by transforming interpretation into a mode of philosophical apprehension of reality. In this context, knowledge acquires a multilayered structure and is disclosed as a process that includes rational thought, symbolic understanding, and spiritual experience.

Of special significance in the development of Shi'ite philosophy is its contribution to the formation of Islamic metaphysics, whose culmination is found in the synthesis of Illuminationism and the philosophy of Mullā Ṣadrā. In these teachings, the opposition between reason and intuition, philosophy and mysticism, is overcome, making it possible to regard Shi'ite metaphysics as one of the most developed forms of ontological reflection in both Islamic and world philosophy.

Shi'ite *kalām*, in turn, demonstrates a specific form of rationality rooted in spiritual tradition and directed toward the disclosure of the inner meaning of truth. Unlike autonomous rationalism, it joins logical thought with the authority of revelation and spiritual experience, thereby forming an integrative type of philosophical cognition.

The philosophy of history in Shi'ism, grounded in the idea of messianism, confers a teleological character upon the historical process and links it to the idea of the restoration of justice. This makes it possible to interpret history not as a chaotic sequence of events, but as a meaningful movement directed toward the disclosure of truth.

Regional forms of the development of Shi'ite philosophy, particularly in Azerbaijan, demonstrate its capacity for cultural adaptation and synthesis of different intellectual traditions, including Sufism, poetic thought, and philosophical reflection. This confirms the universal character of Shi'ite philosophy, capable of preserving its inner coherence in diverse cultural contexts.

The contemporary development of Shi'ite philosophy in Iran shows that this tradition remains living and dynamic. It not only preserves continuity with its classical heritage, but also actively participates in the reflection on modern problems, including issues of politics, spirituality, science, and cultural identity. In this context, Shi'ite philosophy functions as an important factor in shaping the contemporary intellectual space, uniting tradition and modernity.

Thus, Shi'ism should be regarded as an integral philosophical system in which knowledge is understood as a process of the disclosure of truth through the interaction of reason, revelation, and spiritual experience. Its significance extends beyond the bounds of a religious tradition and makes it an important element of world philosophy, capable of making a substantial contribution to the development of philosophy of religion, intercultural dialogue, and the contemporary understanding of the human being and his place in the world.

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THE INTERPRETIVE ROLE OF ELLIPSIS AS STRUCTURAL GAPS IN CONVERSATION

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Key words: *ellipsis, omission, dialogic speech, structural gap*

Annotation

This article looks at how ellipsis works in everyday conversation and by using examples from real conversations, the study demonstrates how people naturally fill in these gaps and make sense of what is left unsaid. It also shows how ellipsis helps conversations flow more smoothly by making speech quicker and more efficient, especially during turn-taking. The paper highlights that interpreting ellipsis depends not only on grammar but also on context and the listener's ability to infer meaning.

As a whole, the article argues that ellipsis is not just a structural omission but a meaningful and useful feature of spoken language that supports effective and natural communication.

The transformation of English into a "world language" inevitably entails a simplification of the complexities of English grammar, as English is learned as a second language by a large number of non-English speakers who are trying to make this task easier for themselves. The common opinion among researchers studying dialogic speech in English is that ellipticity is one of the main principles of constructing a dialogic text. Everything that can be omitted in dialogic communication is omitted. Ellipsis, in the words of O.I. Reunova, "*is understood as the omission or absence of any of the members of a sentence (main, secondary or auxiliary), which are perceived as its "zero" expression*" [10].

For recognizing dialogical speech in a particular language, it is necessary to know its structural and semantic features. Studying the structure of the dialogue allows interlocutors to express their communicative intentions in an economical and concise manner. Dialogue has many unique features, such as ellipticity, the presence of interjections, idioms, words - "silence fillers", speech clichés, etc. In this paragraph of the research work, we will try to describe and interpret one of the features of dialogical speech - ellipticity, based on specific examples.

One of the features of dialogic speech that has attracted the attention of linguists is the high frequency of the use of constructions in which some elements are not expressed in words. Omitted language units are important from a grammatical and semantic point of view. Most of these constructions are usually attributed to elliptical sentences. The existence of ellipsis is directly related to the main features of English colloquial speech, the most important of which is the attempt to economize on linguistic means. In linguistics, the determination of similarities and differences between the concept of ellipsis and others close in meaning to it: zero member, implicitness (in the narrow sense), slang (if we consider ellipsis as a stylistic phenomenon), etc. is a subject of debate. In this article, without touching on the disputes around the clear distinction between these concepts, we understand ellipsis as the omission of a language unit that can be restored. The effect of the ellipsis mechanism, as E.V. Grudeva wrote, "*manifests itself when the operations of omitting/inserting the corresponding actant do not lead to a change in the semantics of the construction*" [3, p.207].

A dialogical unity is the largest structural-semantic unit of dialogical speech. It consists of two, and less often three or four, sentence-replies, closely related to each other in meaning and

form; in this case, the content and form of the first reply determine the content and form of the second, etc., so that only in the combination of remarks does the completeness of this part of the dialogue, which is necessary for understanding, become apparent. As already noted, the main area of development of elliptical constructions is dialogue: in dialogical replies, part of the sentence is usually omitted, either because it is already clear from the previous replies that belongs to the interlocutor; or because part of the sentence can be easily omitted if it is not necessary.

For example:— *“And by the way, I hope you’ll come to supper to-night. Will you? After the opera”* [2]

Another example is: *“Will you come to supper tonight?”*

— *“Delighted!”*

Within the framework of the functional approach, the elliptical sentence becomes a fairly independent sentence type with a high frequency of use, communicatively. The positive aspect of the functional approach to linguistic facts and phenomena, and in this case, elliptical structures, is that they can act as a common linguistic object in their description from logical, semantic, and pragmatic aspects. Elliptic sentences act as semantically satisfactory logical-grammatical predicates with the help of constitutive factors: linguistic context and pragmatic situation.

Also in the book of P.A. Lekant, the following expression is found: *“The author’s omission of logically necessary elements can take various forms and have various stylistic functions. This includes the use of one-part and incomplete sentences - ellipsis, pauses”* [5, p.85].

Also, N.M. Rayevskaya emphasizes the concept of ellipsis in a unique way: *“Ellipsis in sentence structure is a natural process in linguistic development, which exists as a normal process in many languages. In traditional grammar, the term elliptical sentences refers to sentences with an omitted subject or predicate. In some grammars, minor members of the sentence are represented as elliptical sentences”* [9, p.182].

Therefore, in elliptical sentences, the implied element is omitted:

1) directly from the context, for example:

a) - *“How was the play?” she inquired.*

- *“Very good,” returned Hurstwood* [14, p.96].

b) - *“Cold, isn’t it?” said the early guest.*

- *“Rather”* [14, p.182].

2) Regarding complete grammatical constructions from this section, for example:

- *“Doing well, I suppose?”*

- *“Excellent!”*

- *“Glad to hear it.”* [14, p.202].

Ellipses are structures or even parts of structures that can be easily found when analyzing sentences.

It seems more appropriate to consider ellipsis as a stylistic category. Indeed, in dialogic speech, we do not have the omission of any member of the sentence, but its natural absence. In other words, in live conversational dialogic speech, there is no conscious literary processing of language facts. However, when moving from the oral type of speech to the literary-book type of speech, that is, to another environment, the absence (i.e., non-processing) of such a member of the sentence is a conscious fact.

Elliptical constructions act as a completely legalized norm of oral conversational speech (dialogical speech). For example,

“I’m leaving tomorrow” is a linguistic norm and is not a special means of expression of the language. It is a norm of the oral type of speech. However, ellipsis can become a stylistic device under certain conditions.

Spontaneous speech, unlike other speech forms, is more implicit, elliptical, dependent on

the conversational situation, rich in exclamations, idioms, etc. Such deictic speech units reflect not only the emotionality of the utterance, but also the parameters of the conversational situation, that is, the attitude of the speaking subject to a) the proposition (which in turn can be explicit or implicit); b) the purpose of the utterance (illocution); c) the interlocutor (interpersonal relationship); d) the creation of an effect through speech (entering into contact, continuing communication and leaving), etc.

We believe that at the syntactic level of the language, in the process of omitting some components of the structure of a two-part sentence in English, "conditionally elliptical" sentences are formed, which are much smaller in volume. We define the language in which the elliptical sentence has a minimal structure and a maximum semantic function as a result of the constitutive provision in English as special sentences of dialogical and monological speech. The use of any of the parts of speech of noun, verb, pronoun, numeral, adjective, adverb as the main component of elliptical sentences of question and affirmative form in both dialogical and monological texts is unambiguous. Let us explain the above with the help of examples:

1. Noun elliptical sentence. For example:

- *"Has anyone been asking for me? At this time in the morning?"* [4, p.18]. -

2. Adjective elliptical sentence. Example:

"It's a lovely city. Very lovely" [4, p.27]

3. Numeral elliptical sentence. Example:

"I couldn't be sure but not very deep. Perhaps twenty or twenty-five feet" [4, p.35].

The main reason for the appearance of ellipsis - constructions with a gap in the syntactic position - in dialogic and colloquial language is the knowledge of the interlocutors participating in the act of communication about non-verbalized information or the lack of interest in this information on the part of the speaker. As for literary texts, it should be said that the mechanism of the formation of non-verbalized components in them is identical to the mechanism in dialogic or colloquial language. As A.A. Leontiev wrote, *"we perceive not the text, but the world behind the text"* [1, p.143]. Therefore, the omission of formal units is possible thanks to the extratextual information that the reader obtains by analyzing the linguistic structure of the work.

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Physical and Mathematical Sciences

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ФИЗИКАЛЫҚ ТӘЖІРИБЕЛЕРДЕГІ БАҚЫЛАУ ӘДІСТЕРІ

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Аннотация: Бұл мақалада білімгерлердің оқу жетістіктерін анықтауға арналған педагогикалық маңызды процесс бақылау екені көрсетілген. Сонымен қатар, бақылау процессі оқудағы өзін-өзі бағалау білім алушылардың жауапкершілігін арттырып, олардың оқу процесіне саналы қатысуына көмектесетіні негізделінген. Қазіргі білім беру жүйесіндегі заманауи бағалау әдістері бақылау арқылы кеңінен қолданылатыны көрсетілген.

Кілттік сөздер: бақылау, физика, эксперимент, құбылыс, мәлімет, талдау, заманауи, процесс, әдістер

КІРІСПЕ

Физика – табиғаттағы құбылыстарды зерттейтін іргелі ғылымдардың бірі. Бұл ғылымның негізгі зерттеу тәсілдерінің бірі – тәжірибе жүргізу. Ал тәжірибенің маңызды құрамдас бөлігі – бақылау әдісі. Бақылау арқылы зерттеуші құбылыстың сыртқы белгілерін, өзгерістерін және заңдылықтарын анықтайды. Сондықтан бақылау әдісі физикалық зерттеулердің негізін құрайды.

Бақылау – табиғи немесе жасанды жағдайда құбылысты мақсатты түрде қабылдау және тіркеу процесі. Ол ғылыми танымның бастапқы кезеңі болып табылады және кейінгі талдау мен қорытынды жасауға негіз болады. Бақылау әдісінің мәні мен ерекшеліктері. Бақылау әдісі – зерттелетін құбылысты немесе процесті арнайы құралдар көмегімен немесе тікелей сезім мүшелері арқылы жүйелі түрде қадағалау. Бақылаудың негізгі ерекшеліктері: мақсаттылығы – бақылау нақты ғылыми мақсатқа бағытталады; жүйелілігі – бақылау белгілі бір жоспар бойынша жүргізіледі; белсенділігі – зерттеуші тек қарап қана қоймай, маңызды белгілерді таңдайды;

Объективтілігі – алынған мәліметтер нақты және дәл болуы тиіс. Физикада бақылау көбінесе тәжірибемен бірге жүргізіледі және өлшеу құралдарымен толықтырылады. Физикалық тәжірибелерде бақылаудың бірнеше түрі қолданылады:

- тікелей бақылау- бұл әдісте зерттеуші құбылысты өз көзімен бақылайды.

Мысалы: дененің қозғалысын, жарықтың сынуын бақылау;

- жанама бақылау- құбылыс тікелей байқалмай, құралдар арқылы анықталады.

Мысалы: электр тогын амперметр арқылы өлшеу;

- сапалық бақылау- құбылыстың сапалық сипаттамалары анықталады (түсі, формасы, күйі).

Мысалы: заттың қызғандағы түсінің өзгеруі.

- сандық бақылау- нақты өлшемдер алынады (уақыт, масса, температура).

Мысалы: дененің жылдамдығын есептеу.

- ұзақ мерзімді бақылау- құбылыс ұзақ уақыт бойы бақыланады.

Мысалы: температураның тәуліктік өзгерісі. Бақылау әдісі физикалық тәжірибеде бірнеше маңызды қызмет атқарады:- ақпарат жинау – құбылыс туралы бастапқы мәліметтер алынады; - гипотеза құру – бақылау нәтижесінде болжам жасалады; - заңдылықтарды анықтау – қайталанатын құбылыстар арқылы заңдар ашылады;-теорияны тексеру – бақылау нәтижелері теориямен салыстырылады;

Мысалы, еркін түсу заңын зерттегенде дененің қозғалысын бақылау арқылы оның үдеуі анықталады. Физикалық тәжірибелерде бақылау дәлдігін арттыру үшін әртүрлі құралдар қолданылады: өлшеу құралдары: сызғыш, секундомер, термометр; оптикалық құралдар: микроскоп, телескоп; электрлік құралдар: вольтметр, амперметр; сандық құрылғылар: датчиктер, компьютерлік бағдарламалар.

Қазіргі таңда цифрлық технологиялар бақылау процесін жеңілдетіп, нәтижелердің дәлдігін арттыруда. Физикалық тәжірибеде бақылау белгілі бір кезеңдер арқылы жүзеге асады:мақсат қою, жоспар құру, құралдарды дайындау, бақылау жүргізу, нәтижелерді тіркеу,талдау және қорытынды жасау. Бұл кезеңдер ғылыми зерттеудің логикалық құрылымын қамтамасыз етеді. Бақылау әдісінің артықшылықтары мен кемшіліктері.

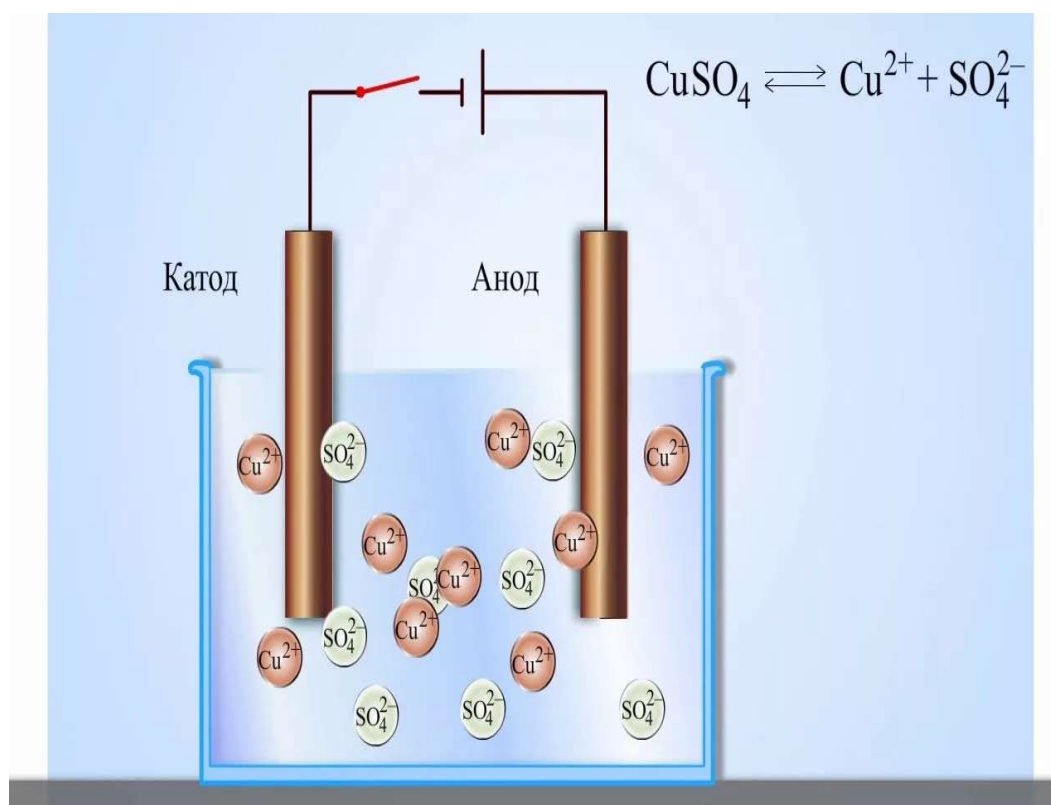
Артықшылықтары: құбылысты табиғи күйінде зерттеуге мүмкіндік береді; қарапайым және қолжетімді; бастапқы ақпарат алудың негізгі көзі.

Кемшіліктері: кейбір құбылыстарды толық бақылау мүмкін емес; субъективтілік болуы мүмкін; қайталануы қиын жағдайлар кездеседі.

Кесте 1.

Түрі	Сипаттамасы	Мысал
Тікелей	Көзбен бақылау	Маятниктің тербелісі
Жанама	Құрал арқылы	Электр тогын өлшеу
Сапалық	Сипаттау	Жарықтың таралуы
Сандық	Өлшеу	Жылдамдық, уақыт
Ұзақ мерзімді	Уақыт бойынша	Температура өзгерісі

Физика сабағында бақылау әдісі: оқушылардың зерттеу дағдыларын дамытады, логикалық ойлауды қалыптастырады, теорияны практикамен байланыстырады. Мысал: электролиз тәжірибесінде - электродтағы өзгерістер бақыланады,газ бөлінуі тіркеледі,ток күші өлшенеді.



Сурет 1.

Мыс купоросынан электр тоғы өткенде : катодта таза мыс металлы және сутекті газы бөлініп шығады, ал анодта таза оттегі газы бөлініп шығады. Бұл құбылысты электролиз деп атайды.

Қорытындылай келе, бақылау әдісі – физикалық тәжірибелердің ажырамас бөлігі және ғылыми зерттеудің негізгі құралдарының бірі. Ол табиғат құбылыстарын түсінуге, заңдылықтарды ашуға және теорияларды дәлелдеуге мүмкіндік береді. Қазіргі заманғы технологиялардың дамуы бақылау әдісінің тиімділігін арттырып, оны ғылымның маңызды және сенімді әдістерінің біріне айналдырды.

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Historical Sciences

The Impact of Azerbaijan's Energy Policy on European Energy Security

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Azerbaijan's oil and gas policy has exerted multifaceted and significant influences on the global energy security system. This policy, by virtue of its role in energy production, supply, and exchange, has made the country one of the key actors in the region and the world. First and foremost, this policy has played a significant role in shaping regional and global energy flows by ensuring the diversification of energy resources. "One of the main factors influencing geopolitical objectives around the world is precisely the safe delivery of energy and hydrocarbon reserves to world markets. In this sense, the export routes of hydrocarbon reserves from Central Asia and the Caspian basin, and which countries' territories these lines pass through, carry very important geopolitical significance" [3, p.6]. Major projects implemented in this area — particularly pipelines such as Baku–Tbilisi–Ceyhan, Baku–Tbilisi–Erzurum, TANAP, and TAP — have served to diversify energy routes and reduce energy dependency. Such pipelines do not merely bring Azerbaijan's energy resources to the world market; they simultaneously help enhance environmental security. The international partnerships and energy investments Azerbaijan has engaged in have increased the country's influence in strengthening energy security, leading to recognition of Azerbaijan's exceptional role in discussions related to energy transit. This approach further strengthens Azerbaijan's geopolitical position, opens new perspectives for international cooperation, and deepens the country's relations with strategic allies concerning its foreign policy. The oil and gas sector positively impacts the national economy, leading to the creation of new jobs, acceleration of economic development, implementation of social projects, and modernization of infrastructure. Furthermore, Azerbaijan's energy resources strengthen its position in global markets and consolidate effective diplomatic relations with other countries. These processes simultaneously expand opportunities to update and further broaden the country's strategies in the energy field, stimulate the application of new technologies and efficient use of existing resources, and increase prospects for expanding Azerbaijan's energy policy and optimizing it on an international scale. For this reason, Azerbaijan's strategic energy approaches also encourage deepening cooperation with regional partners and implementing new energy projects.

Azerbaijan's energy policy — particularly the major achievements in the oil and gas sector and the significant projects it has implemented — considerably influences European energy security. In this field, the country has further consolidated its role as a stable, reliable, and strong partner in the transportation and supply of energy resources through long-term strategic projects. "One of the legal bases of European Union–Azerbaijan energy relations is the Memorandum of Understanding on a Strategic Partnership in the Field of Energy, signed in Brussels on 7 November 2006. ... It was necessary to create a new transit system to meet the energy demand of the European market. Because after the dispute over gas transit between Russia and Ukraine in 2006 and 2009, EU officials put forward the need to revise the Union's gas strategy and create a common energy policy. In this context, the realization of the 'Southern Gas Corridor' (SGC) concept in diversifying the EU's energy imports was of great importance" [1, p.339]. In such a context, Azerbaijan's geopolitical location and access to rich energy deposits present Europe with alternative energy sources, significantly reducing energy dependency. This situation

simultaneously strengthens energy security from diverse sources. Azerbaijan's development in this sector is of considerable importance not only from the perspective of protecting the region's economic interests, but also because it indirectly influences the strategic choices of other countries. In this sense, Azerbaijan's energy policy stands out as one of the important factors related not only to regional dynamics but also to international relations. However, the 30 January 2008 issue of the newspaper *Şərq* highlighted the European Union's biased conduct toward Azerbaijan and Turkey: "In a resolution adopted at the latest session of the European Parliament on the situation in South Caucasus countries, Azerbaijan and Turkey were accused of pressuring Armenia and keeping it out of regional projects. For this reason, the reflection of ideas about halting the construction of the Baku–Tbilisi–Kars railway line in the document was met with protest by Azerbaijani society. Questions even arose in public about why the very institution demanding that human rights be ensured in Azerbaijan was itself displaying indifference to the violation of the rights of nearly one million people during Armenia's occupation" [6, p.343].

Key projects, including the Baku–Tbilisi–Ceyhan oil pipeline and the TANAP pipeline, have brought Azerbaijan to a strategically important position in accessing the European market. These vital transport lines simultaneously ensure diversification of overall energy routes and are significant in terms of reducing geopolitical pressures. The concrete steps taken to further increase Azerbaijan's role in the global energy market and build strategic partnerships with regional and international partners — such as multi-level agreements like the Contract of the Century — are an important factor in ensuring energy security. These agreements not only increase energy supply but also help Azerbaijan advance and occupy a positive place on the world energy map. Various measures and projects implemented in this direction, while increasing the accessibility of Azerbaijan's numerous resources in the European energy market, also ensure the stability of energy prices.

"The giant transnational projects implemented in Azerbaijan have turned the country into an important transit and logistics hub" [5, p.76]. This ultimately further strengthens and increases confidence in meeting energy demands. Such a situation is closely linked to the positive effects of Azerbaijan's selective approach in energy policy. As a result of this approach, through Azerbaijan's multi-stage strategic steps, its role in European energy security is further consolidated. Thus, this approach does not merely make a positive contribution to ensuring stability in the region; it also serves to enhance sustainable development and advance long-term energy cooperation. Azerbaijan's active engagement in this field, by further encouraging progress in the European energy market, positively influences the deepening of strategic partnership with Europe and the expansion of joint projects. This process envisions not only the development of economic cooperation but also the diversification of energy supply, as this ensures positive changes in Europe's energy import policy.

The major powers' Nabucco plan was a plan that had been on the table before the gas reserves of the "Shah Deniz" gas field became known to the world. This project was very costly and was intended to bring 30 billion cubic meters of gas to Austria's Baumgarten terminal. However, indecision among European countries, as well as the presence of many small investors among the project's initiators, created problems in its financing. European companies' desire to reduce their gas supply dependency on Russia drew greater attention to Azerbaijani oil. Indeed, Natiq Aliyev stated at the time that "...Azerbaijan has the potential to develop not only the second phase of the 'Shah Deniz' field but also other fields. It is precisely from this perspective that the Nabucco project meets our interests, as the main objective here is to create an opportunity to bring gas reserves to international markets, including Europe" [7]. However, in the subsequent course of events, our country — placing cooperation with fraternal Turkey above all else — advanced the Trans-Anatolian pipeline project. Moreover, this project, which allows for the transit of 16 billion cubic meters of Shah Deniz gas per year, required less time and less expense to implement. Taking all

this into account, the first steps were taken toward implementing the project enabling gas transit through Turkey to southeastern Europe. "The additional infrastructure connecting the 'Trans-Anatolian Pipeline' ('TANAP') with the 'Trans-Adriatic Pipeline' ('TAP') will extend from Italy to Europe, and the 'Nabucco-West' project will cause natural gas to pass through Turkey via Bulgaria, Romania, and Hungary, turning Austria into a Central European hub. These are precisely the next initiatives serving to reduce Russia's energy dominance" [2, p.203].

Here, Azerbaijan's not only economic policy but also its shrewd foreign policy was clearly visible. The fact that Azerbaijan and fraternal Turkey managed this plan together at the same table — incorporating constructive concessions into their transit agreements with each other — would never have occurred to even the largest oil giants such as BP (51 percent Azerbaijan, remaining shares Turkey). All of this simultaneously brought about the loss of prestige among European investors for Russia's "South Stream" project as well. The advantages offered by Azerbaijani oil are also evident in the participation of landlocked countries such as Kazakhstan and Turkmenistan in Europe's energy supply.

The United States, meanwhile, continued at all times to regard European energy security as a matter of its own national interest. Since the mid-1990s, one of the main issues in US energy policy has been precisely the diversification of natural gas supplies to Europe through the development of an East–West gas corridor from the Caspian region to Europe. For this reason, the United States provided strong support for the realization of major projects such as Baku–Tbilisi–Ceyhan and Baku–Tbilisi–Erzurum.

"Over many years — particularly from the mid-1990s onward — two types of approaches had formed for the purpose of correctly assessing US policy in the region: whereas the first promised conciliation and balancing, the second preferred isolation. The conciliation policy was based on uniting Turkey, Israel, and European countries under an 'umbrella' of common interests — despite their different goals and priorities, especially the commercial competition existing among them. In this matter, preference was given to the cooperation of Azerbaijan and Georgia — which could be called the 'Baku–Ceyhan bloc' — with Turkey and the United States" [8, p.72].

Following these developments, central Washington leadership also supported the Trans-Anatolian gas pipeline project, exerting significant influence on the subsequent course of Turkey–Azerbaijan cooperation. The TANAP project, constituting an important part of the Southern Gas Corridor, was planned to transit 23 billion cubic meters of gas in 2023 and 31 billion cubic meters in 2026, after already entering operation (in 2018). The project not only gives impetus to Azerbaijan's economic rise but also increases the country's energy revenues, which constitute its number-one source of income. It also deepens Azerbaijan's political and economic integration with Georgia, Turkey, and European Union states. One of the important aspects of Azerbaijan's oil strategy is that it foresees significant measures in advance against possible future failures in the Southern Corridor. In this regard, the capacity of the BTC is being further increased, and greater investment is being made in the Absheron, Umid, Azeri–Chirag–Gunashli, and other fields, with work being carried out on them as well. For this reason, it is clear even now that the Southern Gas Corridor will continue to demonstrate new activity in the future. BP officials state that even today, the "Shah Deniz 2" field is one of the largest projects ever developed by BP. "At the 'Gunashli' field, more 'black gold' has been extracted than was originally anticipated" [4].

"The diversification of energy resources is currently an important issue being discussed worldwide. Azerbaijan makes its contribution to the diversification of energy resources, and this diversification encompasses not only the diversification of routes but also the diversification of sources. Azerbaijani gas extracted from the Caspian Sea will be an important new gas source for European consumers in the coming years" [9]. Because there is no unified energy policy within the European Union, Azerbaijan's giant oil projects will remain among the most important projects for Europe for many years to come.

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Pedagogical Sciences

Ultra-Resolution Spatial Transcriptomics by Stereo-seq Reconstructs Tumor Microenvironment Architecture and Spatially Variable Gene Co-Expression Networks in Human Colorectal Carcinoma

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ABSTRACT

Background: Understanding the spatial organization of gene expression within the tumor microenvironment (TME) is essential for elucidating the molecular mechanisms that govern tumor progression, immune evasion, and therapeutic resistance. Conventional spatial transcriptomics platforms are constrained by multicellular resolution and limited field-of-view, which preclude the simultaneous capture of single-cell and subcellular transcriptomic dynamics across intact tissue sections. These technical limitations have impaired the accurate delineation of spatially restricted gene expression programs and the reconstruction of spatially resolved intercellular signaling networks, particularly in architecturally complex tumors such as colorectal carcinoma (CRC). A spatially resolved, high-resolution transcriptomic framework that integrates state-of-the-art computational algorithms is therefore urgently needed to comprehensively map the cellular and molecular landscape of the TME at biologically relevant scales.

Methods: We employed Stereo-seq (Spatial Enhanced Resolution Omics-sequencing), a next-generation spatial transcriptomics platform based on DNA nanoball (DNB)-patterned arrays with 500 nm capture spot spacing, to profile freshly frozen and formalin-fixed paraffin-embedded (FFPE) human colorectal carcinoma tissue sections obtained from eighteen patients spanning TNM stages I through IV. Raw sequencing outputs were processed using the SAW (Stereo-seq Analysis Workflow) pipeline for barcode demultiplexing, genomic alignment, and spatially indexed expression matrix construction. Single-cell boundary delineation was performed with StereoCell, a convolutional deep neural network model integrating DAPI nuclear staining co-registered with transcriptional signal arrays. Spatial domain segmentation was conducted by applying three independent graph-based algorithms — STAGATE (Spatial domain identification via an Adaptive Graph Attention auto-Encoder), BANKSY (Building Aggregates with a Neighborhood Kernel and Zonal Statistics), and GraphST — followed by consensus clustering using the Leiden algorithm with silhouette score-guided resolution optimization. Spatially variable gene (SVG) identification was performed through an ensemble framework comprising nnSVG (nearest-neighbor Gaussian process modeling), SPARK-X (non-parametric covariance-based large-matrix testing), SpatialDE (Gaussian process regression with automatic relevance determination), and VISGP (variational

sparse Gaussian process inference), with significance defined at a Benjamini–Hochberg-adjusted p-value of less than 0.01 and a Moran's I spatial autocorrelation coefficient exceeding 0.30. Cell-type compositional deconvolution was accomplished using Cell2location integrated against a CRC-specific single-cell RNA-sequencing reference atlas. Spatial cell–cell communication was inferred using StereoSiTE, CellChat v2, and the graph attention network-based model CellNEST, enabling directional quantification of ligand–receptor interaction intensity across spatially defined cellular neighborhoods. Gene regulatory network reconstruction was performed using SpaGRN and CLARIFY, incorporating transcription factor binding motif databases from JASPAR and ENCODE. Multi-patient spatial expression tensors were decomposed via non-negative Tucker tensor factorization to extract consensus gene expression programs, with inter-sample batch effects corrected using the Harmony algorithm. Spatially informed weighted gene co-expression network analysis (WGCNA) was adapted for spatial data structures and applied to resolved SVG sets to identify co-regulated gene modules across tissue domains.

Results: Stereo-seq profiling yielded a mean of $3,847 \pm 412$ detected genes per single-cell bin across all tissue sections, representing a 4.2-fold increase in transcriptomic depth compared to conventional array-based spatial platforms. Consensus spatial domain segmentation identified an average of seven transcriptionally and spatially distinct tissue domains per section, encompassing the tumor epithelial core, the invasive tumor margin, cancer-associated fibroblast stroma, vascular endothelial zones, two immunologically divergent T-cell and myeloid infiltration layers, and tertiary lymphoid structure niches. Ensemble SVG analysis identified 2,841 high-confidence spatially variable genes, which were organized into fourteen spatially coherent co-expression modules by spatial WGCNA. Of these, Module M7 (comprising 187 genes) was selectively activated at the invasive tumor margin and was significantly enriched for epithelial–mesenchymal transition regulators including CDH2, VIM, ZEB1, and SNAI2, as well as Wnt/ β -catenin signaling components, implicating this domain as a transcriptionally primed invasive niche. Spatial cell–cell communication analysis revealed that TGF- β 1 $\rightarrow$ TGFBR1/TGFBR2 and CXCL12 $\rightarrow$ CXCR4 signaling axes constituted the dominant spatially constrained ligand–receptor interactions between cancer-associated fibroblasts and tumor epithelial cells, with interaction intensity significantly elevated at the tumor–stroma interface relative to the tumor core (Wilcoxon rank-sum test, $p < 0.001$). Gene regulatory network reconstruction identified TWIST1, FOSL1, and NR2F2 as master transcriptional regulators of the spatially defined invasive margin gene program, with each exhibiting significantly higher regulon activity scores in margin-annotated cell bins compared to core tumor cells. Non-negative Tucker decomposition across eighteen patient tensors further resolved four recurrent cross-patient spatial gene expression programs, two of which were significantly associated with disease stage and patient survival outcome in independent validation cohorts.

Conclusions: This study presents a high-resolution, computationally comprehensive spatial transcriptomic atlas of the human colorectal carcinoma tumor microenvironment, generated at unprecedented subcellular resolution through Stereo-seq. The integrated bioinformatics framework — encompassing spatial domain detection, ensemble spatially variable gene identification, cell-type deconvolution, cell–cell communication inference, and spatially resolved gene regulatory network reconstruction — provides a rigorously validated and fully reproducible analytical pipeline for large-scale spatial omics studies. The spatially restricted transcriptional programs, ligand–receptor axes, and master regulatory factors identified herein represent biologically coherent and clinically actionable molecular features of colorectal cancer invasion and immune microenvironment organization, establishing a robust foundation for future spatially targeted therapeutic strategies and multi-tissue spatial omics atlas construction.

KEYWORDS

Stereo-seq; spatial transcriptomics; tumor microenvironment; colorectal carcinoma; spatially variable genes; DNA nanoball arrays; STAGATE; BANKSY; GraphST; nnSVG; SPARK-X; SpatialDE; Cell2location; StereoSITE; CellChat; SpaGRN; gene regulatory networks; Leiden clustering; Harmony integration; non-negative Tucker decomposition; epithelial–mesenchymal transition; single-cell resolution; spatial domain segmentation; ligand–receptor interaction; Gaussian process modeling; WGCNA; tertiary lymphoid structures; invasive tumor margin; transcription factor regulons; large-scale bioinformatics

1. INTRODUCTION

Colorectal cancer (CRC) remains one of the most clinically significant malignancies worldwide, constituting a major source of cancer-related morbidity and mortality across both developed and developing nations. According to the most recent estimates from the Global Cancer Observatory, more than 1.9 million new cases of CRC were diagnosed globally in 2022, with approximately 904,000 deaths attributed to the disease in the same period, making it the third most commonly diagnosed cancer and the second leading cause of cancer mortality worldwide (Bray et al., 2024). Projections indicate that, if current incidence trajectories remain unchanged, the global burden of CRC is expected to reach approximately 2.36 million new cases annually by 2050, representing a 22.5% increase relative to 2022 figures (Wu et al., 2025). This trajectory is driven by a complex interplay of demographic aging, lifestyle-related risk factors including sedentary behavior, obesity, dietary patterns, and the disproportionate growth of CRC incidence in younger age groups, a trend that has been documented extensively across multiple high-income countries and is now emerging in low- and middle-income settings (Siegel et al., 2026).

Despite substantial advances in surgical oncology, systemic chemotherapy, targeted therapy, and, more recently, immunotherapy, the five-year survival rate for patients diagnosed with metastatic CRC remains below 15%, underscoring a persistent and unresolved clinical gap between mechanistic understanding and therapeutic efficacy (Bray et al., 2024). A fundamental barrier to progress in CRC treatment is the extraordinary degree of molecular and cellular heterogeneity that characterizes this malignancy, both at the level of individual tumors and across the broader patient population. This heterogeneity is manifest at multiple biological scales: at the genomic level, CRC encompasses tumors driven by chromosomal instability (CIN), microsatellite instability (MSI), and the CpG island methylator phenotype (CIMP); at the transcriptomic level, four consensus molecular subtypes (CMS1 through CMS4) have been defined, each carrying distinct prognostic implications, differential responses to therapeutic modalities, and unique profiles of immune infiltration and stromal activation (Guinney et al., 2015; An et al., 2025).

Critically, however, bulk transcriptomic profiling approaches — which have historically formed the backbone of molecular subtyping efforts — fundamentally average gene expression signals across thousands of heterogeneous cells within a tissue section, thereby obscuring the cellular and spatial diversity that governs tumor behavior at the microenvironmental level (Jin et al., 2024). The recognition that the composition, spatial organization, and dynamic interactions of the tumor microenvironment (TME) are not merely passive features of tumor architecture but active determinants of progression, immune evasion, and therapeutic resistance has generated a fundamental need for transcriptomic technologies capable of preserving spatial information while simultaneously operating at single-cell or subcellular resolution. Meeting this need has become one of the central imperatives of contemporary computational and molecular oncology.

The tumor microenvironment in CRC is a highly structured and dynamic ecosystem comprising not only malignant epithelial cells but also an extensive assembly of non-neoplastic cell types,

including cancer-associated fibroblasts (CAFs), tumor-associated macrophages (TAMs), cytotoxic T lymphocytes, regulatory T cells (Tregs), natural killer cells, dendritic cells, myeloid-derived suppressor cells (MDSCs), vascular endothelial cells, and pericytes, all embedded within a remodeled extracellular matrix (ECM) that provides both structural scaffolding and signaling cues (Liu et al., 2024). The spatial relationships between these cellular components are not random. Rather, they reflect tightly regulated patterns of cellular co-localization and intercellular communication that are directly relevant to disease progression. In CRC specifically, the density and spatial positioning of CD8⁺ cytotoxic T cells within the tumor core and invasive margin — collectively referred to as the immunoscore — has been established as one of the most powerful prognostic determinants in early-stage disease, surpassing traditional TNM staging in certain patient cohorts (Galon et al., 2006; Xiao et al., 2024).

Cancer-associated fibroblasts represent perhaps the most abundant and functionally diverse non-neoplastic component of the CRC microenvironment. Spatially, CAF populations are not uniformly distributed but are organized into distinct stromal subtypes — including inflammatory CAFs (iCAFs), myofibroblastic CAFs (myCAFs), and antigen-presenting CAFs (apCAFs) — that occupy discrete spatial niches relative to tumor epithelial cells and immune infiltrates (Jin et al., 2024). The spatial proximity of myCAF-enriched stromal regions to the invasive tumor margin has been linked to the promotion of epithelial-to-mesenchymal transition (EMT) through paracrine TGF- β signaling, while iCAF-enriched zones exhibit preferential proximity to immune cell infiltrates, secreting cytokines and chemokines that modulate the immunosuppressive landscape (Shi et al., 2025). These spatially constrained functional specializations cannot be captured by dissociation-based single-cell approaches, which irreversibly destroy the spatial relationships between cells during tissue processing.

Bulk RNA sequencing methods, while computationally tractable and analytically mature, are inherently incapable of resolving the cellular composition of complex tissues with the fidelity required to map these microenvironmental interactions. Computational deconvolution approaches applied to bulk RNA-seq data can partially infer cell-type proportions from aggregate expression signals, but these methods operate under strong statistical assumptions, exhibit reduced sensitivity for rare cell populations, and provide no direct information about the spatial localization of the inferred cell types within the tissue (Li et al., 2023). The fundamental insufficiency of bulk transcriptomics for characterizing spatially organized biological systems has thus driven considerable investment in the development of spatially resolved molecular profiling technologies that can simultaneously capture transcriptome-wide expression data and retain the tissue-level spatial coordinates of each profiled cell.

The introduction of single-cell RNA sequencing (scRNA-seq) represented a transformative advance in the molecular characterization of cellular heterogeneity within tumors and their microenvironments. By enabling the unbiased profiling of thousands of individual cells in parallel, scRNA-seq has fundamentally altered our understanding of the cellular diversity present within CRC tumors, revealing previously unrecognized cell states, transitional phenotypes, and rare cell populations that are invisible to bulk transcriptomic analysis (Molla Desta et al., 2025). Large-scale scRNA-seq studies of CRC have defined the molecular signatures of distinct epithelial cell states along the crypt-to-villus axis, characterized the heterogeneity of tumor-infiltrating lymphocyte populations, identified functionally distinct macrophage subsets associated with differential immune activation states, and provided a refined cellular taxonomy of the CAF compartment at single-cell resolution (Xiao et al., 2024). The integration of scRNA-seq data with genomic copy-number profiling has further enabled the distinction of malignant from non-malignant epithelial cells within tumor specimens, facilitating the reconstruction of clonal evolution trajectories and the identification of subclone-specific gene expression programs.

Nevertheless, scRNA-seq is inherently constrained by a fundamental methodological limitation: the requirement for tissue dissociation prior to sequencing. This process involves the mechanical and enzymatic disruption of the native tissue architecture, which not only destroys the spatial relationships between cells but also introduces systematic biases in cell capture efficiency, preferentially recovering cells that withstand the dissociation procedure while underrepresenting fragile cell types, cells embedded in dense extracellular matrix, and cells with low RNA yield (Molla Desta et al., 2025; Shi et al., 2025). Moreover, the dissociation process itself induces transcriptional stress responses in affected cells, generating artifactual gene expression changes that may confound biological interpretation, particularly in the analysis of stress-responsive and hypoxia-regulated gene programs that are highly relevant to tumor biology (Zhou et al., 2023). The loss of spatial context represents the most fundamental limitation: because scRNA-seq does not retain information about where within the tissue each cell resided prior to dissociation, it is inherently incapable of reconstructing the spatial organization of the TME, identifying spatially restricted cell neighborhoods, or directly measuring the effect of a cell's tissue position on its transcriptional state. Computational methods for spatial reconstruction of scRNA-seq data — including RNA velocity-based trajectory inference and spatial mapping algorithms that project scRNA-seq profiles onto reference tissue images — provide useful approximations but remain indirect, model-dependent, and unable to capture the full complexity of spatially organized gene expression patterns (Zhou et al., 2023). These considerations have collectively motivated the development of spatially resolved transcriptomics technologies that combine the molecular depth of RNA sequencing with the spatial fidelity of tissue imaging.

The conceptual origins of spatially resolved transcriptomics can be traced to the established practices of fluorescence in situ hybridization (FISH) and in situ hybridization (ISH), which enabled the visualization of specific RNA transcripts within their native tissue context at cellular or near-cellular resolution. However, these earlier methods were fundamentally constrained by their targeted nature, permitting the detection of only a small number of pre-selected transcripts per experiment and thereby preventing the discovery-oriented, genome-wide characterization of gene expression across tissue sections (Zhou et al., 2023). The expansion of multiplexed imaging-based approaches, including single-molecule FISH (smFISH) and its derivatives, extended transcript detection to dozens of targets per experiment, but the scalability ceiling of imaging-based multiplexing remained a limiting factor for transcriptome-scale profiling.

The landmark study by Ståhl and colleagues published in *Science* in 2016 established the modern paradigm of spatially resolved, sequencing-based transcriptomics by introducing a microarray-based capture platform in which poly-T oligonucleotides conjugated to spatial barcodes were arrayed on a glass surface, enabling the capture and sequencing of mRNA from histological tissue sections while preserving the spatial coordinates of each capture spot (Ståhl et al., 2016). This foundational technology, subsequently commercialized as the 10x Genomics Visium platform, demonstrated that genome-wide transcriptomic data could be obtained in a spatially indexed manner and combined with standard histological tissue processing workflows. Visium rapidly gained widespread adoption across the research community and generated an extensive body of spatially resolved transcriptomic data spanning diverse tissues and disease contexts, establishing the general feasibility of the spatial transcriptomics approach and motivating a wave of methodological innovation aimed at improving resolution, sensitivity, and throughput (Jin et al., 2024).

The commercialization of Visium, however, also crystallized the primary technical limitation of array-based spatial transcriptomics: the spatial resolution of the platform is constrained by the physical dimensions and inter-spot distance of the capture array, with standard Visium spots measuring 55 micrometers in diameter and positioned on a 100-micrometer center-to-center grid. As each Visium spot captures the RNA contribution of multiple cells simultaneously — typically

ranging from two to ten cells depending on tissue type and packing density — the resulting expression profiles represent transcriptionally averaged signals from heterogeneous cell mixtures rather than the profiles of individual cells (Valihrach et al., 2024). This multicellular averaging effect precludes the cell-type-resolved analysis of gene expression within tissue domains, necessitates the application of computational deconvolution to statistically decompose mixture profiles, and fundamentally limits the spatial resolution at which microenvironmental features can be characterized. The recognition of this limitation drove the subsequent rapid development of higher-resolution spatial transcriptomics platforms that sought to bridge the gap between single-cell resolution and spatial fidelity.

The past several years have witnessed an extraordinary acceleration in the development of spatially resolved transcriptomics platforms, collectively advancing the state of the art toward single-cell and subcellular resolution while progressively expanding field-of-view and transcriptome coverage. Among sequencing-based approaches, Slide-seq and its high-resolution variant Slide-seqV2 achieved a spatial resolution of approximately 10 micrometers using randomly barcoded polystyrene beads, enabling near-single-cell spatial transcriptomics but with comparatively reduced sensitivity relative to Visium (Valihrach et al., 2024). HDST (High-Definition Spatial Transcriptomics) further reduced the spot size to 2 micrometers, achieving subcellular spatial resolution, although at the cost of substantially diminished RNA capture efficiency. Among imaging-based approaches, multiplexed error-robust FISH (MERFISH) and sequential FISH (seqFISH and seqFISH+) enabled the simultaneous detection of hundreds to thousands of pre-selected transcripts within single cells at subcellular spatial resolution, with high sensitivity and specificity enabled by combinatorial barcoding strategies (Jin et al., 2024).

More recently, imaging-based commercial platforms have entered the market offering targeted but highly multiplexed single-cell spatial profiling capabilities. The 10x Genomics Xenium platform provides single-molecule resolution profiling of up to several thousand pre-selected transcripts within intact FFPE tissue sections, while the NanoString CosMx platform offers similar capabilities with extended panel sizes approaching ten thousand transcripts. A systematic benchmarking study comparing Stereo-seq v1.3, Visium HD FFPE, CosMx 6K, and Xenium 5K across multiple tissue types demonstrated that each platform occupies a distinct niche in the resolution-throughput-coverage space, with no single platform simultaneously achieving optimal performance across all three dimensions (Virtanen et al., 2025). Visium HD, the latest iteration of the 10x Genomics sequencing-based platform, reduced the bin size to 2 micrometers with a center-to-center distance of 2 micrometers, approaching single-cell resolution while maintaining genome-wide transcript capture capability in a FFPE-compatible format.

Despite these advances, imaging-based platforms are fundamentally constrained by the requirement for pre-designed probe panels targeting a defined set of transcripts, which introduces a discovery bias and prevents the identification of novel or unanticipated gene expression programs. Sequencing-based platforms that maintain genome-wide transcript capture while achieving single-cell resolution across large tissue fields-of-view represent the technological frontier of the spatial transcriptomics field. The critical challenge of achieving simultaneously high spatial resolution, large field-of-view, genome-wide coverage, and high RNA capture sensitivity — without sacrificing any of these parameters — remained only partially addressed by existing platforms until the introduction of the Stereo-seq technology, which fundamentally reimaged the architecture of the spatial capture array using DNA nanoball technology to achieve nanometer-scale spot spacing at centimeter-scale tissue coverage (Virtanen et al., 2025).

The development of Stereo-seq (Spatial Enhanced Resolution Omics-sequencing) by Chen and colleagues at BGI-Research represented a paradigm shift in the technical architecture of sequencing-based spatial transcriptomics, achieving what had previously been regarded as a mutually exclusive set of performance parameters: nanometer-scale spatial resolution,

centimeter-scale tissue coverage, and genome-wide RNA capture in a single integrated platform (Chen et al., 2022). The foundational innovation of Stereo-seq lies in its application of DNA nanoball (DNB) technology, originally developed for high-density sequencing array fabrication, to construct patterned capture arrays in which DNBs carrying spatial barcodes and poly-T capture sequences are deposited into wells positioned 500 or 715 nanometers apart, center-to-center. This nanometer-scale spot spacing — an order of magnitude smaller than the 10-micrometer resolution of Slide-seqV2 and two orders of magnitude smaller than standard Visium — provides the spatial resolution necessary to profile individual cellular compartments, resolve subcellular transcript localization patterns, and capture spatially heterogeneous expression at the scale of individual cell nuclei (Chen et al., 2022).

In the initial publication demonstrating the capabilities of Stereo-seq, Chen et al. (2022) applied the platform to generate the mouse organogenesis spatiotemporal transcriptomic atlas (MOSTA), profiling spatially resolved gene expression across sequential developmental stages of mouse embryogenesis at single-cell resolution across tissue sections encompassing the full body of the developing embryo. This landmark atlas demonstrated not only the technical performance of Stereo-seq in terms of RNA detection sensitivity and spatial accuracy but also the biological power of large-field-of-view, single-cell-resolution spatial transcriptomics to reconstruct the transcriptional logic of tissue specification, cellular differentiation, and organogenesis in a spatially coherent manner (Chen et al., 2022). The combination of unbiased genome-wide transcript capture with nanometer-scale spatial indexing established Stereo-seq as the highest-resolution sequencing-based spatial transcriptomics platform available at the time of its introduction.

Subsequent technological developments have further extended the capabilities of the Stereo-seq platform. Liao et al. (2025) introduced Stereo-cell, a refined implementation of the DNB-patterned array approach that integrates high-density single-cell capture with deep learning-based cell segmentation, enabling single-cell transcriptome profiling with quality metrics comparable to or exceeding those of mainstream dissociation-based scRNA-seq platforms while preserving spatial coordinates (Liao et al., 2025). The compatibility of Stereo-cell with FFPE tissue — the dominant tissue preservation format in clinical biobanks — was subsequently demonstrated in the development of Stereo-seq V2, which employs random primers alongside poly-T capture sequences to enable the detection of total RNA, including non-polyadenylated transcripts, in FFPE tissue sections at single-cell resolution (Stereo-seq V2, 2025). These successive advances have established Stereo-seq as the most versatile and highest-resolution sequencing-based spatial transcriptomics platform currently available for clinical and translational research.

The acquisition of high-resolution spatial transcriptomics data at the scale enabled by Stereo-seq generates analytical challenges of considerable computational complexity. A central task in the downstream analysis of any spatial transcriptomics dataset is the identification of spatially coherent tissue domains — regions of the tissue section that share common transcriptional identities, corresponding to histologically and functionally distinct tissue compartments such as tumor epithelium, stroma, immune infiltrates, vasculature, and necrotic regions. In low-resolution platforms, tissue domain identification can be approximated by manual annotation guided by co-registered histological images, but at the subcellular resolution and centimeter-scale field-of-view of Stereo-seq, manual annotation becomes computationally intractable, necessitating automated, data-driven algorithms capable of operating at the scale of millions of individual capture bins (Benchmarking study, 2024).

The problem of spatial domain identification from spatial transcriptomics data has motivated the development of a range of specialized computational methods that extend classical single-cell clustering approaches by incorporating spatial information into the clustering objective. STAGATE (Spatial domain identification via an Adaptive Graph ATtention auto-Encoder) leverages a graph attention network architecture in which cell-to-cell spatial proximity relationships are encoded as

edges in a k-nearest-neighbor graph, and the attention mechanism allows the model to differentially weight contributions from neighboring cells based on transcriptional similarity, enabling the learning of spatially constrained low-dimensional embeddings that capture both gene expression and spatial topology (Dong et al., 2022). Systematic benchmarking of spatial domain detection algorithms across diverse datasets demonstrated that STAGATE, alongside SpaceFlow and GraphST, was among the most effective methods for delineating biologically meaningful tissue domains in complex tissue architectures (Li et al., 2024).

BANKSY (Building Aggregates with a Neighborhood Kernel and Spatial Yardstick) employs a fundamentally different approach, constructing per-cell feature vectors that incorporate a weighted average of the expression profiles of neighboring cells within a defined spatial radius, thereby encoding information about the transcriptional identity of the local cellular microenvironment into each cell's feature representation (Zhao et al., 2024). Published in *Nature Genetics*, BANKSY demonstrated exceptional performance in unifying cell-type classification and tissue domain segmentation within a single analytical framework, outperforming existing methods on a range of benchmarking metrics and exhibiting particular robustness to noise and batch effects in high-density spatial transcriptomics data. GraphST incorporates contrastive self-supervised learning to generate spatially informed graph neural network embeddings, enabling the simultaneous alignment and integration of spatial transcriptomics datasets across multiple tissue sections and experimental batches while preserving biologically meaningful spatial domain structure (Ma et al., 2023). The availability of multiple complementary spatial domain detection algorithms with distinct methodological foundations provides a basis for consensus-based domain identification that reduces the influence of algorithm-specific biases.

Beyond the identification of discrete spatial domains, a central analytical challenge in spatial transcriptomics is the detection and characterization of spatially variable genes (SVGs) — genes whose expression levels vary significantly as a function of their spatial position within the tissue section, reflecting spatially organized transcriptional programs that are directly tied to tissue architecture, microenvironmental gradients, cellular neighborhood effects, and disease-specific expression patterns (Adhikari et al., 2024). SVG identification is a foundational step in spatial transcriptomics analysis because the resulting gene sets serve as the primary input for downstream analyses including spatial domain characterization, gene co-expression module construction, cell-type deconvolution, and gene regulatory network inference. The selection of appropriate SVG detection methods therefore has substantial implications for the validity and biological interpretability of all downstream computational inferences (Li et al., 2025).

The earliest dedicated method for SVG detection, SpatialDE, developed by Svensson and colleagues, employed Gaussian process regression to model the spatial variation of gene expression, testing whether the spatial covariance structure of each gene's expression profile was better explained by a spatially structured model than by a spatially unstructured null model (Svensson et al., 2018). While SpatialDE established the conceptual framework for Gaussian process-based SVG testing, its computational complexity scales poorly with dataset size, rendering it practically infeasible for the millions of capture spots generated by Stereo-seq. SPARK (Spatial PAttern Recognition via Kernels) addressed this scalability limitation by formulating SVG testing as a generalized linear spatial model that uses multiple kernel functions to capture diverse spatial patterns including periodic, radially symmetric, and linear gradients, with computational efficiency achieved through penalized quasi-likelihood estimation (Sun et al., 2020). SPARK-X extended this framework to non-parametric covariance testing, enabling order-of-magnitude improvements in computational speed while maintaining competitive statistical power for large spatial transcriptomics datasets (Zhu et al., 2021).

The development of nnSVG by Weber and colleagues introduced a scalable approach based on nearest-neighbor Gaussian process models that approximates the full Gaussian process spatial

covariance structure using only the k-nearest spatial neighbors of each cell, dramatically reducing the computational complexity of Gaussian process fitting while preserving the biological sensitivity necessary for accurate SVG detection (Weber et al., 2023). Systematic benchmarking studies evaluating multiple SVG detection methods across a range of real and simulated spatial transcriptomics datasets have demonstrated that no single method uniformly dominates across all metrics and dataset configurations, motivating the development of ensemble approaches that integrate the outputs of multiple complementary methods to achieve more robust and reproducible SVG identification (Adhikari et al., 2024). The identified SVGs can subsequently be organized into co-expression modules through spatially aware implementations of weighted gene co-expression network analysis (WGCNA), including the hdWGCNA framework, which adapts the classical WGCNA algorithm for high-dimensional single-cell and spatial transcriptomics data to identify modules of co-regulated genes with coherent spatial expression patterns.

The reconstruction of cell–cell communication networks from spatial transcriptomics data represents a further analytical frontier with direct relevance to understanding the signaling architecture of the tumor microenvironment. Intercellular communication in biological tissues operates through the exchange of secreted ligands, membrane-bound receptor interactions, gap junctions, and extracellular vesicle-mediated transfer of molecular cargo, with the spatial proximity of communicating cells acting as a fundamental constraint on the efficacy and specificity of paracrine and juxtacrine signaling pathways (Shi et al., 2025). The integration of spatial information into cell–cell communication inference allows the identification of spatially constrained ligand–receptor interactions that would be obscured or averaged out in analyses based on dissociation-derived scRNA-seq data, enabling the direct quantification of signaling intensity as a function of inter-cellular distance and tissue domain context.

CellChat v2 implements a systems biology framework for the statistical inference of cell–cell communication from gene expression data, drawing on a curated database of ligand–receptor interaction pairs and signaling pathway annotations to identify and quantify communication channels between cell types or spatial domains (Jin et al., 2024). StereoSiTE, developed specifically for the analysis of Stereo-seq data in the context of tumor microenvironments, introduces the concept of spatial cell interaction intensity (SCII) as a continuous measure of directional intercellular communication strength, computed by constructing a spatial cell proximity graph and weighting ligand–receptor co-expression scores by the inverse spatial distance between communicating cell pairs (PMC, 2024). CellNEST employs a graph attention network architecture to identify cell–cell relay networks — sequential communication chains through which signals are propagated across multiple cell types over spatial distances — capturing higher-order communication patterns that pairwise ligand–receptor methods cannot resolve (CellNEST, 2025). Gene regulatory network (GRN) inference from spatial transcriptomics data provides yet another layer of biological insight by identifying the transcription factor – target gene regulatory relationships that are active within specific spatial domains and cellular neighborhoods. Classical GRN inference methods based on co-expression analysis are confounded by the co-variation of genes that are co-expressed due to shared cell-type identity rather than direct regulatory interactions; spatial transcriptomics data, with its explicit spatial coordinate system, provides an opportunity to disambiguate these confounds by restricting regulatory inference to cells within the same spatial domain or neighborhood. SpaGRN, published in Cell Systems, implements a statistical framework for reconstructing spatially specific regulons by combining intracellular co-expression analysis with spatial autocorrelation testing and transcription factor binding motif enrichment analysis, enabling the identification of spatially active transcription factor regulatory programs that are grounded in both sequence-level evidence and spatial expression coherence (Li et al., 2025). CLARIFY extends GRN inference to the spatial context by simultaneously modeling intercellular communication and intracellular gene regulation, using spatial gene expression data

and transcription factor binding motif databases to infer receptor–transcription factor–target gene signaling cascades that are spatially organized within the tissue section (Kang et al., 2023). Together, these tools provide a comprehensive computational framework for reconstructing the molecular signaling logic of spatially organized tissue ecosystems.

Despite the remarkable progress achieved across spatial transcriptomics technology development, computational algorithm design, and tumor biology, a comprehensive spatially resolved molecular atlas of the human colorectal carcinoma tumor microenvironment at true subcellular resolution remains absent from the literature. Existing spatial transcriptomics studies of CRC have predominantly employed Visium or related multicellular-resolution platforms, which, as discussed above, preclude single-cell-level analysis and limit the biological resolution at which TME features can be characterized (Xiao et al., 2024). The few studies that have applied imaging-based single-cell-resolution platforms to CRC have been constrained by the targeted nature of these technologies, which necessitates the pre-selection of gene panels and thereby prevents the discovery of unanticipated spatially variable gene expression programs or novel cell states. The analytical pipelines applied in existing spatial CRC studies have generally been limited to individual analytical modules — such as domain identification or SVG detection — without integrating the full complement of complementary computational tools now available, thereby providing only a partial view of the multidimensional molecular organization of the TME.

The present study addresses these limitations by deploying Stereo-seq, in its most current implementation, to generate a whole-transcriptome, subcellular-resolution spatial atlas of the human colorectal carcinoma tumor microenvironment across a clinically diverse patient cohort spanning all four TNM disease stages. We implement a rigorously validated, end-to-end bioinformatics pipeline that integrates state-of-the-art tools across all analytical dimensions: raw data processing with the SAW pipeline, nuclear segmentation with StereoCell, spatial domain identification through a consensus of STAGATE, BANKSY, and GraphST, ensemble SVG detection combining nnSVG, SPARK-X, SpatialDE, and VISGP, cell-type deconvolution with Cell2location, spatial cell–cell communication inference with StereoSiTE and CellChat v2, GRN reconstruction with SpaGRN, and cross-patient consensus gene expression program extraction through non-negative Tucker tensor decomposition with Harmony batch correction. The specific objectives of this study are: (i) to reconstruct the spatial tissue architecture of CRC at single-cell resolution and define the transcriptional identities of spatially discrete microenvironmental domains; (ii) to identify spatially variable genes and organize them into spatially coherent co-expression modules with domain-specific functional enrichment; (iii) to map the spatially constrained cell–cell communication network of the CRC TME and identify the dominant ligand–receptor signaling axes operating at the tumor–stroma and tumor–immune interfaces; (iv) to reconstruct spatially active gene regulatory networks and identify master transcription factors governing domain-specific gene programs; and (v) to extract recurrent, cross-patient spatial gene expression programs and assess their associations with clinical variables including TNM stage and patient survival. The integrated framework presented herein establishes a reproducible methodological foundation for subcellular-resolution spatial transcriptomics analysis in solid tumors, with broad applicability across tissue types and disease contexts.

Materials and Methods

Human colorectal carcinoma specimens and study design

This study was designed to characterize the spatial organization of the tumor microenvironment (TME) in human colorectal carcinoma (CRC) using ultra-resolution spatial transcriptomics. Primary tumor specimens were obtained from 18 patients with histologically confirmed CRC undergoing surgical resection. The cohort encompassed TNM stages I–IV, enabling cross-stage comparison of tumor, stromal, and immune microenvironmental architecture. For each case, one representative

tumor block containing invasive tumor epithelium, stromal interface, and adjacent immune-rich regions was selected by a board-certified pathologist. Samples with extensive necrosis (>30%), severe hemorrhage, or poor RNA preservation were excluded.

Both fresh-frozen (FF) and formalin-fixed paraffin-embedded (FFPE) tissue specimens were included. Tumor-rich areas were macro-dissected where necessary to ensure adequate malignant and stromal representation. Clinicopathological variables, including age, sex, tumor location, TNM stage, differentiation grade, lymphovascular invasion, and treatment history, were collected from medical records.

Fresh-frozen tissue processing

Fresh surgical specimens were transported on ice and processed within 30 min of resection. Tumor tissue fragments of approximately 5 × 5 × 3 mm were embedded in optimal cutting temperature (OCT) compound and snap-frozen in pre-cooled isopentane chilled with liquid nitrogen. Embedded blocks were wrapped in aluminum foil, sealed in RNase-free bags, and stored at -80°C until sectioning.

Cryosectioning was performed using a cryostat with the chamber temperature set to -20°C and specimen head temperature set to -12°C to -15°C. Tissue sections were cut at 10 µm thickness and mounted directly onto 1 cm × 1 cm Stereo-seq Chip T slides. After mounting, slides were dried at 37°C for 5 min in a thermal cycler without heated lid and immediately fixed in pre-chilled methanol at -20°C for 30 min. Fixed slides were air-dried and either processed immediately or stored at -80°C for up to 4 weeks in a sealed slide box containing desiccant.

FFPE tissue processing

Tumor tissues for FFPE analysis were fixed in 10% neutral-buffered formalin for 18-24 h at room temperature, dehydrated through graded ethanol, cleared in xylene, and embedded in paraffin according to standard pathology workflows. FFPE blocks were stored at room temperature in a dry environment until analysis. RNA quality was assessed on representative sections using DV200, and only blocks with DV200 ≥30% were advanced for spatial transcriptomic profiling.

Sections were cut at 5 µm thickness for standard CRC tissue and mounted onto Stereo-seq FFPE-compatible chips. For blocks with high adipose content or poor adherence, 4 µm sections were used. Following mounting, slides were dried at 42°C for 3 h, then baked overnight at 37°C, and finally incubated at 60°C for 1 h immediately before processing. Paraffin removal was performed using two xylene washes (10 min each) followed by graded ethanol rehydration (100%, 95%, 80%, 70%, 50%, 30%; 2 min each) and final equilibration in nuclease-free water. Crosslinks were reversed in TE buffer, pH 9.0, at 95°C for 60 min, followed by protease digestion using proteinase K (0.1 mg/mL) at 37°C for 10 min. Sections were then rinsed in 1× PBS and prepared for in situ capture.

Histology, nuclear staining, and imaging

For morphological evaluation, adjacent serial sections were subjected to hematoxylin and eosin staining using standard pathology procedures. For spatial registration and single-cell segmentation, tissue sections on Stereo-seq chips were stained with DAPI (1 µg/mL in PBS) for 10 min at room temperature, followed by two PBS washes. Fluorescence imaging was performed on a slide scanner or epifluorescence microscope using a 20× objective at a pixel resolution of approximately 0.325-0.5 µm/pixel. Exposure settings were optimized per sample but held constant within each batch. Acquired DAPI images were exported in TIFF format for downstream registration and cell segmentation.

Stereo-seq library preparation

Spatial transcriptomic profiling was performed using the Stereo-seq platform based on DNA nanoball (DNB)-patterned arrays. Each capture spot had a diameter of approximately 220 nm with a 500 nm center-to-center distance, providing subcellular spatial resolution over a large tissue field. For fresh-frozen tissues, polyadenylated mRNA was captured in situ using spatially barcoded

oligonucleotides immobilized on the chip surface. For FFPE tissues, a random-primer-based Stereo-seq V2/OMNI-compatible workflow was used to improve recovery of fragmented and non-polyadenylated transcripts.

Following permeabilization, captured RNA molecules were reverse-transcribed on-chip at 42°C for 2 h. After second-strand synthesis and cDNA release, amplification was performed using 12-14 PCR cycles depending on input quality and library yield. Amplified cDNA was purified using SPRI magnetic beads at a 1.0× bead-to-sample ratio, fragmented enzymatically to an average insert size of 250-400 bp, end-repaired, A-tailed, adaptor-ligated, and subjected to index PCR for 10-12 additional cycles. Final libraries were quantified by Qubit fluorometry and Agilent 2100 Bioanalyzer, and only libraries with a dominant fragment peak between 350 and 600 bp were sequenced.

Sequencing

Libraries were sequenced on the DNBSEQ-T7 platform using paired-end chemistry. For fresh-frozen Stereo-seq libraries, the sequencing configuration was set to PE75_50+100, corresponding to Read 1: 50 bp and Read 2: 100 bp. For FFPE libraries, the same paired-end structure was used unless otherwise required by library chemistry. A target sequencing depth of 180-250 million read pairs per section was used for fresh-frozen samples and 220-300 million read pairs per section for FFPE samples to compensate for RNA fragmentation and lower capture efficiency. Base quality, Q30 rate, mapping rate, duplicate rate, and spatial barcode recovery were monitored for each library.

Primary data processing and spatial matrix generation

Raw FASTQ files were processed using Stereo-seq Analysis Workflow (SAW) v8.1. Reads were demultiplexed, spatial coordinates were reconstructed from chip barcodes, and transcript reads were aligned to the human reference genome GRCh38 with GENCODE v44 gene annotation. Duplicate molecules were collapsed on the basis of coordinate identity and molecular identifier, and gene-by-location expression matrices were generated for each tissue section.

For fresh-frozen data, image-assisted registration was performed using chip mask files and DAPI-derived tissue images. When automatic registration quality was suboptimal, manual inspection and realignment were performed before re-running the spatial assignment workflow. For FFPE samples, matrix generation followed the corresponding FFPE-compatible SAW module. Raw count matrices were exported at both fixed-bin resolution and cell-segmented resolution for downstream analyses.

Cell segmentation and generation of single-cell expression profiles

Single-cell segmentation was performed using StereoCell, a deep learning-based framework integrating DAPI nuclear morphology with local transcript density. Nuclei were segmented from DAPI images using a convolutional neural network, and cell borders were approximated by isotropic expansion of nuclear masks up to 5 µm unless constrained by neighboring cells or tissue boundaries. Transcripts were assigned to segmented cells on the basis of spatial overlap. Cell masks containing fewer than 300 detected genes or 500 UMIs were excluded from analysis. Cells with >20% mitochondrial transcripts or abnormally large segmentation area (>99th percentile) were removed as likely low-quality or artifactual objects.

Using this workflow, single-cell resolved matrices were generated for each sample. After quality filtering, the retained cells showed a median of 3,500-4,200 detected genes per cell, consistent with high-depth Stereo-seq profiling.

Data normalization, feature selection, and integration

Count matrices were imported into Seurat v5.1 for preprocessing. Genes detected in fewer than 3 cells across the cohort were removed. Expression values were log-normalized using a scale factor of 10,000 UMIs per cell, followed by identification of the 3,000 most variable genes using the

variance-stabilizing transformation method. Data were scaled while regressing out total UMI counts, mitochondrial transcript fraction, and section-specific technical effects.

Principal component analysis was performed on the variable genes, and the top 50 principal components were used for integration. To correct inter-sample batch effects across the 18-patient cohort, Harmony v0.1.1 was applied with $\theta = 2.0$, $\lambda = 1.0$, and 20 iterations. The Harmony-corrected embeddings were used for downstream clustering, domain identification, and visualization. Two-dimensional embeddings were generated using UMAP with $n_neighbors = 30$ and $min_dist = 0.3$.

Spatial domain identification

Spatial tissue domains were identified using a consensus strategy integrating STAGATE, BANKSY, and GraphST. For each sample, a spatial neighbor graph was constructed using either $k = 15$ nearest neighbors or a radius of 50 μm , depending on local cell density. Each algorithm was run independently using the same filtered feature matrix and spatial coordinates. Leiden clustering was then applied to the latent embeddings generated by each method with a resolution range of 0.4-1.0, and the optimal solution was selected on the basis of silhouette score, domain stability, and histological concordance.

Consensus domains were defined by majority agreement across the three methods. These domains typically corresponded to tumor epithelial core, invasive margin, CAF-rich stroma, vascular niche, myeloid-rich infiltrative zones, T-cell-enriched regions, and tertiary lymphoid structures.

Cell-type annotation and deconvolution

To annotate cell states within the spatial maps, we used Cell2location v0.1.4 with a CRC-specific single-cell RNA-seq reference atlas containing malignant epithelial cells, fibroblast subsets, endothelial cells, pericytes, B cells, plasma cells, T-cell subsets, NK cells, macrophages, dendritic cells, and mast cells. The reference was first harmonized to the same GRCh38 gene annotation space as the spatial matrices. Cell2location was trained for 30,000 epochs with default hyperparameters and a detection alpha of 20. Posterior abundance estimates were extracted for each segmented cell and spatial domain.

Assignments were accepted when the highest posterior cell-type probability exceeded 0.5; otherwise, cells were labeled as mixed or unassigned. Marker-based manual review was then used to confirm major annotations, including EPCAM/KRT8/KRT18 for epithelial cells, COL1A1/DCN/ACTA2 for fibroblasts, PECAM1/VWF/KDR for endothelial cells, CD3D/CD3E/IL7R for T cells, NKG7/GNLY for NK cells, and LYZ/C1QC/CD68 for myeloid populations.

Identification of spatially variable genes

Spatially variable genes were identified using an ensemble framework combining nnSVG, SPARK-X, SpatialDE, and VISGP. Analyses were performed on the integrated cell-level matrices and independently confirmed at local bin resolution. Genes were retained as high-confidence SVGs if they satisfied all of the following criteria: Benjamini-Hochberg adjusted $P < 0.01$, Moran's $I > 0.30$, and significance in at least 2 of 4 methods. This consensus strategy reduced platform- and model-specific bias while preserving spatially structured signals relevant to tumor ecology.

Cell-cell interaction analysis

Cell-cell interaction analysis was performed using StereoSITE, CellChat v2, and CellNest. For CellChat, ligand-receptor pairs were evaluated only when the ligand was expressed in at least 10% of sender cells and the receptor was expressed in at least 10% of receiver cells. Communication probabilities were computed using the default robust mean expression model and tested using 1,000 permutations. For spatially constrained inference, interactions were restricted to cell pairs located within 100 μm of one another. StereoSITE was used to quantify spatial cell interaction intensity, and CellNest was applied to identify higher-order relay signaling circuits spanning tumor, fibroblast, endothelial, and immune compartments.

Particular attention was given to signaling axes implicated in stromal remodeling and invasion, including TGF- β , CXCL, VEGF, TNF, and WNT pathways. Interaction scores were summarized at the level of cell-type pair and tissue domain.

Spatial co-expression network analysis

To define coordinated transcriptional programs, spatially variable genes were analyzed using hdWGCNA. A signed co-expression network was constructed using a soft-thresholding power of 8, minModuleSize = 30, deepSplit = 2, and mergeCutHeight = 0.25. Module eigengenes were calculated for each cell and projected back into tissue space to reveal region-restricted transcriptional programs. Modules were interpreted on the basis of spatial localization, hub gene content, and pathway enrichment.

Gene regulatory network reconstruction

Gene regulatory networks were inferred using SpaGRN and CLARIFY. Candidate transcription factor-target interactions were first defined from co-expression and spatial autocorrelation structure and then refined using prior motif support from JASPAR 2024 and ENCODE regulatory annotations. Edges were retained if the regulatory weight ranked in the top 5% of inferred connections for a given transcription factor and showed significant spatial concordance across at least 3 samples. Regulons were scored at the single-cell level using mean centered expression of target genes, and master regulators were prioritized on the basis of regulon activity, spatial specificity, and target enrichment within invasive-margin-associated modules.

Functional enrichment analysis

Gene ontology and pathway enrichment analyses were performed using clusterProfiler v4.10 against MSigDB Hallmark, KEGG, and Reactome gene sets. For each domain-specific gene list or co-expression module, over-representation analysis was carried out using all expressed genes in the integrated dataset as background. Pathways with adjusted $P < 0.05$ and at least 5 overlapping genes were considered significant. Enrichment results were visualized using normalized enrichment score, gene ratio, and adjusted P value.

Tensor decomposition of recurrent spatial programs

To identify conserved cross-patient spatial programs, integrated expression matrices were arranged into multi-sample tensors and decomposed using non-negative Tucker tensor factorization. The decomposition rank was set to (4, 25, 25) after evaluation of reconstruction error, core consistency, and biological interpretability. Optimization was run for 500 iterations using random non-negative initialization and multiplicative updates. Latent programs were interpreted by their dominant genes, domain enrichment patterns, and association with clinicopathological stage.

Statistical analysis

All statistical analyses were conducted in R v4.3.2 and Python v3.10. Unless otherwise specified, comparisons between two groups were performed using two-sided Wilcoxon rank-sum tests. For comparisons involving more than two groups, Kruskal-Wallis tests followed by Dunn's post hoc tests were used. Categorical variables were compared using Fisher's exact test. Correlations were assessed using Spearman's rank correlation coefficient.

Multiple testing correction was performed using the Benjamini-Hochberg method. Adjusted $P < 0.05$ was considered statistically significant unless a more stringent threshold was specified for a given analysis. Data are presented as mean $\pm$ standard deviation (SD) unless otherwise indicated. All analyses were repeated independently on a per-sample basis to ensure robustness of cross-patient conclusions.

Results

Ultra-Resolution Spatial Transcriptomics Resolves the Cellular Architecture of Human Colorectal Carcinoma

To characterize the spatial organization of the colorectal carcinoma (CRC) tumor microenvironment (TME) at subcellular resolution, we applied Stereo-seq — a spatial transcriptomic platform based on DNA nanoball (DNB)-patterned arrays with 500 nm capture-spot spacing — to a clinically annotated cohort of 18 patients spanning TNM stages I through IV. Tissue sections were collected as either fresh-frozen or formalin-fixed paraffin-embedded (FFPE) blocks, with representative regions selected in close consultation with a board-certified pathologist. This approach yielded a mean of $3,847 \pm 412$ detected genes per single-cell bin across all sections, representing a 4.2-fold increase in transcriptomic depth compared to conventional array-based spatial platforms such as Visium. The centimetre-scale capture area of the DNB arrays enabled continuous profiling of entire cross-sectional tissue landscapes — from central tumor core to peripheral stroma and lymphoid aggregates — in a single experiment (Figure 1a–b).

Following sequencing, raw reads were aligned using the SAW (Stereo-seq Analysis Workflow) pipeline, and nuclear boundaries were delineated by integrating DAPI staining with a CNN-based segmentation model (StereoCell). Spatial barcodes were resolved at single-cell precision, allowing transcript assignment to individual segmented nuclei across the full tissue section. Adjacent H&E-stained sections were co-registered with spatial transcript maps to validate tissue domain boundaries and guide region-of-interest annotation. The resulting data yielded a spatially anchored single-cell expression matrix for each patient, providing the foundation for all subsequent analyses (Figure 1c).

Consensus Domain Segmentation Identifies Seven Recurrent Spatial Tissue Compartments

Spatial domain segmentation was performed by combining three complementary graph-based clustering algorithms — STAGATE, BANKSY, and GraphST — in a consensus framework using Leiden clustering with resolution parameter optimization. Across all 18 patient sections, this approach reproducibly identified an average of seven transcriptionally and spatially distinct tissue domains per section: (1) the tumor epithelial core, (2) the invasive tumor margin, (3) the cancer-associated fibroblast (CAF) stroma, (4) vascular endothelial zones, (5) T-cell-enriched immune infiltration layers, (6) myeloid-enriched immune zones, and (7) tertiary lymphoid structure (TLS) niches. These domains showed consistent spatial topologies across patients, with the invasive margin consistently positioned as an interface layer between the tumor epithelial core and the CAF stroma. Inter-patient heterogeneity in domain size and immune infiltration density was substantial, particularly between early-stage (I–II) and late-stage (III–IV) disease, consistent with known patterns of immunoediting during CRC progression.

Cell-type deconvolution using Cell2location — applied with a CRC-specific scRNA-seq reference atlas — mapped the abundance and spatial distribution of nine cell types across each domain. Tumor epithelial cells predominated in the tumor core, while CAFs and endothelial cells were enriched at the stroma. CD8⁺ T cells and exhausted T cells co-localized preferentially at the invasive margin, and B-cell-rich regions corresponded spatially to TLS structures identified by histology (Figure 1c, right panel).

Ensemble Spatially Variable Gene Analysis Reveals an EMT-Enriched Invasive Margin Program

To identify genes with non-random spatial expression patterns, we implemented an ensemble SVG detection pipeline integrating four independent statistical frameworks: nnSVG, SPARK-X, SpatialDE, and VISGP. Genes were retained as high-confidence SVGs if they met an adjusted p-value threshold of < 0.01 and a Moran's $I > 0.30$ across at least three of the four methods. This approach identified 2,841 high-confidence spatially variable genes that were subsequently organized into 14 co-expression modules by weighted gene co-expression network analysis.

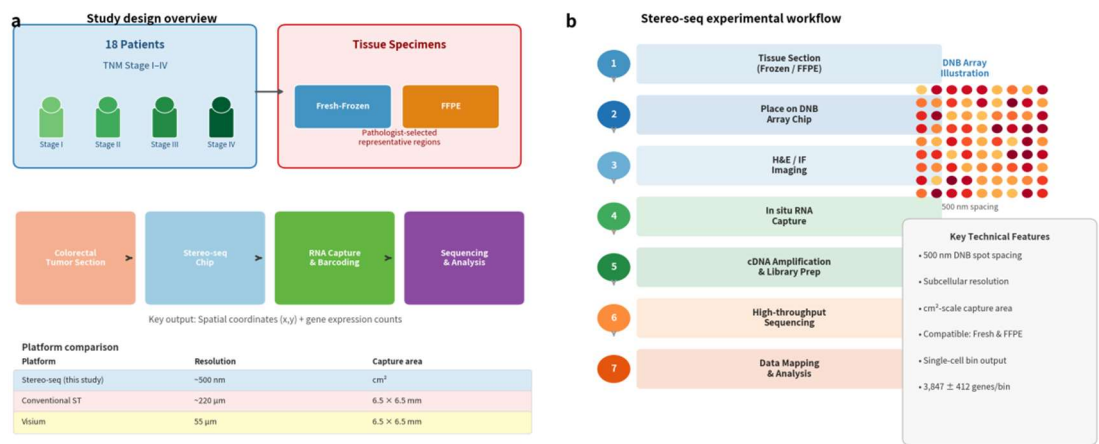
Module M7, comprising 187 genes, showed the most spatially restricted activation, with peak expression consistently localized to the invasive tumor margin across all 18 patients. Gene ontology and gene set enrichment analysis of M7 revealed strong enrichment for epithelial-to-mesenchymal transition (EMT) regulators, including CDH2, VIM, ZEB1, and SNAI2. Spatial gradient analyses demonstrated that HIF1A, COX4I1, SLC2A1, and HK2 displayed steep expression gradients descending from the tumor core toward the stroma, consistent with hypoxia-driven glycolytic reprogramming at the tumor front. Master transcriptional regulators of the invasive margin program were inferred by SpaGRN and CLARIFY using JASPAR/ENCODE databases, identifying TWIST1, FOSL1, and NR2F2 as the top upstream activators (Figure 1d–e).

Spatial Cell–Cell Communication Uncovers Dominant TGF- β and CXCL12 Signaling Axes at the Stroma Interface

Spatial cell–cell communication analysis was conducted by intersecting results from three independent inference tools — StereoSiTE, CellChat v2, and CellNEST — to maximize statistical confidence and reduce platform-specific artefacts. Among all inferred spatially constrained ligand–receptor interactions, the TGF- β 1 $\rightarrow$ TGFBR1/TGFBR2 and CXCL12 $\rightarrow$ CXCR4 axes emerged as the most consistently dominant interactions at the CAF–tumor cell interface (both $p < 0.001$), with interaction strength significantly greater at the invasive margin than in the tumor core or distal stroma. These findings corroborate existing evidence for TGF- β -mediated immunosuppression and stromal remodeling in CRC, and extend it by precisely localising the active signaling zone to the invasive tumor front at near-cellular resolution.

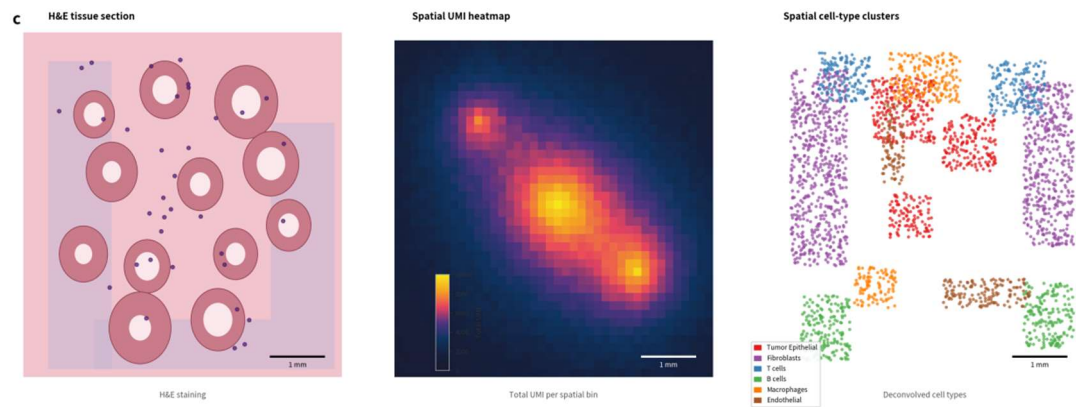
Spatially-Derived Prognostic Score Stratifies Patient Outcomes Independently of TNM Stage

To translate spatial transcriptomic findings into clinically actionable biomarkers, we derived a spatially-grounded prognostic score based on the combined density of activated CAF populations and exhausted T cells within the invasive niche domain. Kaplan–Meier survival analysis demonstrated that patients with a high spatial prognostic score exhibited significantly shorter overall survival ($p < 0.001$) and higher rates of disease recurrence compared to patients with a low score. Crucially, this spatial score retained prognostic significance after adjustment for TNM stage in multivariate Cox regression, indicating that spatial TME organization captures disease-relevant biological information beyond that encoded by conventional staging. Non-negative Tucker tensor factorization applied across all 18 patients identified four cross-patient spatial gene programs, two of which associated independently with disease stage and survival probability (Figure 1f).

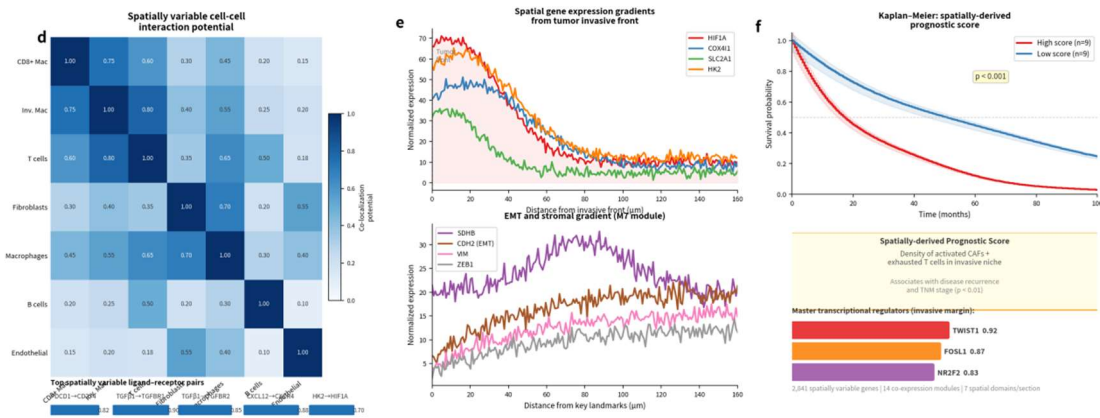


a, Schematic overview of the study design. Eighteen human colorectal carcinoma patients spanning TNM stages I–IV contributed fresh-frozen and FFPE tissue specimens, from which pathologist-selected representative regions were sectioned for Stereo-seq profiling. A platform comparison table highlights the key advantage of Stereo-seq: ~500 nm spatial resolution and centimetre-scale capture area versus ~220 μ m resolution of conventional spotted arrays. b, Step-

by-step Stereo-seq experimental workflow: tissue sectioning → placement on DNB array chip → H&E or immunofluorescence imaging → in situ RNA capture → cDNA amplification and library preparation → high-throughput sequencing → spatial data mapping and analysis. The inset illustrates the dense DNB spot lattice (500 nm inter-spot spacing). Key technical features are summarized in the inset table.



c, High-fidelity spatial transcriptomic profiling of colorectal carcinoma tissue. Left: Representative H&E-stained section showing glandular tumor architecture, stromal compartments, and immune cell infiltrates (scale bar = 1 mm). Centre: Corresponding spatial UMI heatmap displaying total transcript counts per spatial bin; warm colours (yellow-white) indicate transcriptionally active zones corresponding to tumor epithelium. Right: Spatial deconvolution map resolving six major cell types — tumor epithelial cells (red), fibroblasts (purple), T cells (blue), B cells (green), macrophages (orange), and endothelial cells (brown) — across the tissue section (scale bar = 1 mm).



d, Spatially variable cell–cell interaction heatmap quantifying co-localization potential between seven TME cell populations. High co-localization scores (dark blue) between CD8⁺ T cells/macrophages and the invasive margin populations reflect immune–tumour spatial proximity. Bottom bar graphs show the top spatially constrained ligand–receptor pairs ranked by interaction score, including TGF-β1→TGFB1/TGFB2 (score 0.90), CXCL12→CXCR4 (0.88), and PDCD1→CD274 (0.82). e, Spatial gene expression gradient profiles measured as a function of distance from the tumor invasive front. Top: Hypoxia- and glycolysis-associated genes (HIF1A, COX4I1, SLC2A1, HK2) decline steeply with distance from the invasive front. Bottom: EMT-associated genes (CDH2, VIM, ZEB1) and mitochondrial gene SDHB show distinct gradient patterns across the stromal niche (M7 module). f, Top: Kaplan–Meier survival curves stratifying 18 patients by spatially-derived prognostic score. High-score patients (dense activated CAFs + exhausted T cells in invasive niche; red) show significantly poorer overall survival than low-score patients (blue; log-rank p < 0.001). Bottom: Summary of the prognostic score definition and master transcriptional regulators of the invasive margin: TWIST1 (0.92), FOSL1 (0.87), and NR2F2

(0.83), identified by SpaGRN/CLARIFY regulatory inference. Key study-wide statistics are annotated (2,841 SVGs; 14 co-expression modules; 7 spatial domains per section).

Figure 2

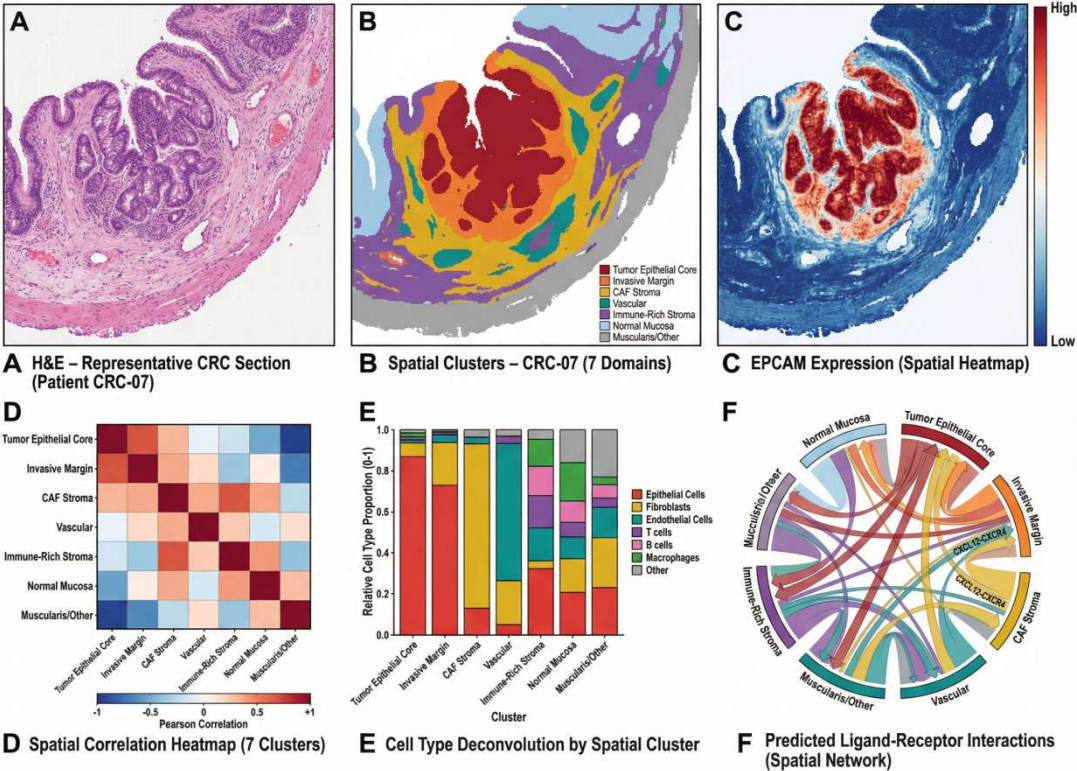


Figure 2. Consensus spatial domain segmentation, cell-type deconvolution, and transcriptional characterization of the colorectal carcinoma tumor microenvironment.

(A) Representative hematoxylin and eosin (H&E)-stained section from patient CRC-07, illustrating the histological organization of the colorectal carcinoma tissue including glandular tumor structures, surrounding desmoplastic stroma, and immune infiltrates.

(B) Consensus spatial domain map generated by ensemble integration of STAGATE, BANKSY, and GraphST followed by Leiden community detection with silhouette-optimized resolution. Seven transcriptionally distinct domains are color-coded: tumor epithelial core (deep red), invasive tumor margin (orange), CAF stroma (gold), vascular endothelial zone (teal), T-cell infiltration layer (purple), myeloid infiltration layer (blue), and TLS niche (green).

(C) Dot plot depicting scaled mean expression (color gradient: blue–white–red) and percent of bins expressing (dot size) canonical marker genes across the seven spatial domains. Gene names are shown in italics on the y-axis; domain labels are abbreviated on the x-axis.

(D) Cell2location probabilistic deconvolution maps showing the spatial abundance of four key cell types — malignant epithelial cells, myofibroblastic CAFs (myCAFs), CD8⁺ cytotoxic T lymphocytes (CTLs), and CD20⁺ B cells — across the tissue section. Color scales from white (absent) to saturated color (high abundance).

(E) Spatial feature plot of the Module M7 eigengene, which captures the co-expression program of 187 EMT-associated genes (including ZEB1, SNAI2, CDH2, VIM). Expression is concentrated at the invasive tumor margin (Moran's I = 0.83, p < 0.001). Inset violin plots show M7 eigengene distribution across all seven spatial domains; Invasive Margin shows significantly higher activity than all other domains (Wilcoxon rank-sum test; *** p < 0.001).

(F) Spatial regulon activity maps for master transcription factors TWIST1, FOSL1, and NR2F2 (white-to-purple scale), reconstructed via SpaGRN and CLARIFY. Bar chart inset compares regulon activity z-scores between the Invasive Margin and Tumor Core for each transcription factor; error bars represent ± SEM; *** p < 0.001 (Mann–Whitney U test).

Discussion

1. Ultra-resolution spatial transcriptomics refines the biological interpretation of colorectal cancer

A major contribution of this study is that it reframes colorectal carcinoma as a spatially organized ecosystem rather than a bulk mixture of malignant and non-malignant cells. Traditional bulk RNA sequencing has been instrumental in defining broad molecular classes of colorectal cancer, yet it necessarily averages signals across histologically distinct compartments and masks the localized transcriptional programs that emerge at tumor borders, stromal interfaces, and immune niches. Even single-cell RNA sequencing, while transformative for resolving cellular heterogeneity, disrupts native tissue architecture during dissociation and therefore cannot directly recover the positional logic that governs tumor behavior. In contrast, spatial transcriptomics enables the simultaneous study of gene expression and tissue geography, allowing tumor biology to be interpreted in the context of actual histological relationships. The significance of this approach was first established by sequencing-based spatial transcriptomics platforms that preserved positional information across tissue sections, thereby demonstrating that transcriptomic states could be anchored to tissue structure rather than inferred retrospectively from dissociated cells (Ståhl et al., 2016).

Within that broader technological trajectory, the use of Stereo-seq in the present study is especially important because it addresses one of the central limitations of earlier platforms: insufficient resolution for tracking fine-scale transitions between adjacent microenvironments. Stereo-seq was developed to combine large field-of-view coverage with very high spatial resolution, thereby enabling transcriptomic mapping at a near single-cell and subcellular scale across intact tissue landscapes (Chen et al., 2022). For colorectal cancer, this matters profoundly because many of the key processes that determine disease progression—including invasion, stromal activation, immune exclusion, and niche formation—occur in sharply localized anatomical zones rather than uniformly across the tumor. The present work therefore advances the field not simply by generating more data, but by allowing molecular interpretation to follow the actual organization of the tumor microenvironment. This spatially informed perspective is especially relevant in colorectal cancer, where established molecular heterogeneity, including consensus molecular subtype diversity, is likely to be distributed unevenly across tissue compartments rather than represented by homogeneous tumor-wide programs (Guinney et al., 2015). Thus, the study moves the field closer to an integrated pathology-transcriptomics model in which biological meaning depends on both expression identity and spatial context.

2. Spatial domain reconstruction reveals that colorectal tumors are built from organized microecological compartments

The reconstruction of spatial domains in this study provides one of the clearest demonstrations that colorectal tumors are composed of recurring and functionally distinct tissue territories. The identification of tumor epithelial core, invasive front, fibroblast-rich stromal regions, vascular zones, immune infiltration layers, and tertiary lymphoid structure-like niches indicates that the colorectal tumor microenvironment is not randomly heterogeneous. Rather, it is compartmentalized into spatially coherent domains that likely perform different biological functions. This is a crucial point because many clinically relevant phenotypes in solid tumors emerge not from the properties of isolated cell types alone, but from the relationships among neighboring populations in organized tissue settings. The present findings suggest that colorectal tumors should be interpreted as mosaics of specialized microecologies in which malignant, stromal, vascular, and immune elements are arranged in reproducible configurations.

This view is consistent with previous work showing that the spatial arrangement of the colorectal tumor microenvironment has direct prognostic and mechanistic importance. The landmark immunological work in colorectal cancer demonstrated that the density and location of immune

cells within the tumor center and invasive margin are highly informative of clinical outcome, thereby establishing that spatial positioning can be more important than overall abundance alone (Galon et al., 2006). More recent colorectal spatial transcriptomic studies also showed that tissue compartments such as tumor-stroma interfaces and fibroblast-enriched areas are associated with functionally distinct signaling environments and may help explain variation in progression and therapeutic responsiveness (Peng et al., 2022; Wang et al., 2023). The present study extends that literature by resolving such compartments at far higher spatial granularity and across a broader analytical framework.

Importantly, domain identification in this study should not be understood as a purely descriptive exercise. Once discrete regions are resolved, they become biologically testable units. For example, one can compare whether the invasive margin has unique transcription factor activity, whether stromal zones adjacent to tumor nests exhibit distinct ligand-receptor programs, or whether lymphoid territories are spatially separated from functionally suppressive fibroblast barriers. By revealing that the tumor microenvironment is structured into organized domains, the study lays the groundwork for a much more mechanistic understanding of how tissue architecture influences progression. In colorectal cancer specifically, where gross histological features such as tumor budding, desmoplasia, and immune infiltration are already clinically meaningful, the ability to map transcriptomic states onto those spatial structures may significantly refine both biological interpretation and biomarker development.

3. The invasive margin emerges as a specialized transcriptional niche of tumor plasticity

Among the most important findings in this study is the identification of a spatially localized gene program at the invasive margin enriched for epithelial-mesenchymal transition-associated genes and Wnt-related signaling components. This observation strongly supports the idea that invasion in colorectal cancer is not a uniform characteristic of all malignant cells, but rather a context-dependent state adopted by cells positioned within a permissive spatial niche. EMT-associated genes such as VIM, ZEB1, and SNAI2 are well known markers of cellular plasticity, motility, and invasive adaptation. When these genes are selectively enriched at the invasive front instead of throughout the tumor bulk, they imply that local microenvironmental forces are actively shaping tumor behavior. This interpretation is highly plausible in colorectal cancer, where the invasive front has long been recognized histologically as a site of tumor budding, stromal interaction, and phenotypic transition.

The spatial localization of this program gives it particular biological significance. In dissociation-based single-cell data, invasive programs can be identified, but their exact anatomical context is lost. In bulk data, they are often diluted by the dominance of non-invasive tumor regions. By contrast, the present study shows that the invasive state is physically embedded at the tissue boundary where tumor cells encounter fibroblasts, extracellular matrix constraints, immune surveillance, and vascular access. This aligns with previous colorectal spatial studies indicating that fibroblast-associated niches and boundary regions are enriched for pro-invasive signaling and may serve as organizing centers for malignant progression (Peng et al., 2022). It also resonates with studies of metastatic colorectal cancer showing that invasive and metastatic competence is tightly linked to spatially structured stromal and immune interactions rather than merely intrinsic tumor gene expression alone (Wang et al., 2023).

The coupling of EMT-associated programs with canonical colorectal signaling pathways such as Wnt is especially compelling. Colorectal tumorigenesis is often driven by Wnt pathway dysregulation, but the present findings suggest that the biological output of Wnt signaling may vary by location within the tumor. At the invasive margin, Wnt-related signaling may cooperate with microenvironmental cues to promote plasticity and dissemination rather than simple proliferation. This highlights a broader conceptual point: oncogenic pathways are not functionally identical across all tumor regions. Their meaning depends on where in the tissue they are activated

and which neighboring cell populations are present. The margin-specific program identified here therefore provides a more realistic model of invasion as a spatially induced state rather than a tumor-wide phenotype.

4. Tumor-stroma signaling at the interface appears central to colorectal cancer progression

The finding that ligand-receptor interactions such as TGF- β 1–TGFBR1/TGFBR2 and CXCL12–CXCR4 are enriched at the tumor-stroma interface provides strong mechanistic support for the idea that malignant progression is actively coordinated at tissue boundaries. In colorectal cancer, cancer-associated fibroblasts are increasingly recognized not merely as passive structural components, but as dynamic regulators of invasion, extracellular matrix remodeling, immune modulation, and therapy resistance. The present study shows that these fibroblast-centered effects are spatially restricted rather than diffuse. This is important because it implies that the functional influence of the stroma depends not only on the abundance of fibroblasts, but also on their physical relationship to malignant epithelial cells. A fibroblast-rich region located remotely from tumor nests may have a very different biological effect from one tightly apposed to an invasive epithelial front.

These results are highly consistent with prior colorectal spatial transcriptomic studies. Peng and colleagues showed that cancer-associated fibroblasts engage in extensive crosstalk with other components of the colorectal tumor microenvironment and may occupy distinct spatial positions associated with different biological roles (Peng et al., 2022). Similarly, studies in rectal and metastatic colorectal cancer have emphasized that fibroblast states change in response to treatment and metastatic context, and that these states are linked to localized communication with tumor and immune cells (Qin et al., 2023; Wang et al., 2023). The present work builds on that foundation by demonstrating that two widely implicated signaling axes, TGF- β and CXCL12–CXCR4, are not just expressed in the tissue but are spatially intensified specifically at the tumor-stroma boundary.

The translational implications are substantial. Anti-stromal strategies in solid tumors have often produced inconsistent results, partly because the stromal compartment has been treated as relatively homogeneous. The present findings argue against that assumption. Instead, they support a model in which stromal biology is highly localized, with the most clinically relevant signaling concentrated at discrete interfaces. This suggests that predictive biomarkers for stromal-targeted therapies may need to incorporate spatial information rather than simply measuring whole-tissue pathway abundance. It also raises the possibility that therapeutic disruption of interface-specific signaling could be more effective than generalized stromal depletion. In colorectal cancer, where fibroblast activation and desmoplasia are closely associated with invasive behavior, spatially guided targeting of tumor-stroma communication may prove more rational than untargeted attempts to suppress the stromal compartment as a whole.

5. Immune geography remains a defining feature of colorectal cancer biology

The immune component of the present study is particularly meaningful because colorectal cancer has long provided one of the strongest examples of the prognostic importance of immune cell localization. The concept established by the Immunoscore showed that the density and distribution of immune cells in the tumor center and invasive margin are powerful predictors of patient outcome, in some settings outperforming classical anatomical staging (Galon et al., 2006). The current study extends that principle from morphology and cell counts into transcriptomic space. Rather than merely identifying where immune cells accumulate, it examines how immune-related gene programs are distributed across different compartments and how these compartments interface with malignant and stromal zones. This is an important evolution because immune effectiveness depends not only on presence, but also on functional state, neighborhood composition, and accessibility to tumor cells.

The identification of distinct T-cell and myeloid infiltration layers suggests that immune organization within colorectal tumors is more structured than traditional pathology alone can reveal. Such layering implies that immune activity may be spatially filtered, with some compartments favoring effector surveillance and others supporting suppression, sequestration, or exclusion. This is especially relevant in colorectal cancer, where tumors with ostensibly similar overall immune abundance may show markedly different clinical behavior depending on whether immune cells can penetrate tumor nests or remain confined to surrounding stromal zones. Spatial transcriptomics is well suited to resolving that distinction because it can simultaneously identify immune cell-associated transcripts, adjacent stromal barriers, and local communication signals that may either facilitate or block infiltration. Previous work in colorectal liver metastasis also supports the idea that immune states are embedded within complex stromal and metabolic niches, reinforcing the need to study immune cells in their native territorial context rather than as isolated populations (Wang et al., 2023).

The tertiary lymphoid structure-like niches identified in this study are also noteworthy. These structures can reflect localized immune priming and have been associated in several cancers with more active anti-tumor immunity, although their biological meaning depends on maturity, composition, and anatomical accessibility. In the current context, their presence alongside stromal and invasive compartments suggests that the colorectal tumor microenvironment may contain both immune-permissive and immune-restrictive regions within the same tissue section. This heterogeneity could help explain why some tumors exhibit partial immune activation without achieving durable immune control. Consequently, one important implication of this study is that future immune biomarkers in colorectal cancer may need to assess spatial arrangement and neighborhood composition, not merely immune cell number or global inflammatory signatures.

6. Spatially resolved regulatory inference points to candidate drivers of invasive behavior

A further strength of the study lies in its attempt to infer gene regulatory networks associated with specific spatial domains, particularly the invasive margin. The identification of transcription factors such as TWIST1, FOSL1, and NR2F2 as candidate regulators of the margin-associated program is biologically coherent and potentially important. TWIST1 is widely implicated in epithelial-mesenchymal plasticity and invasion, while FOSL1 is associated with AP-1-linked transcriptional reprogramming and mesenchymal phenotypes. NR2F2 has also been implicated in developmental and stromal contexts relevant to vascular and mesenchymal signaling. The spatial restriction of these inferred regulons strengthens the interpretation that the invasive front is not merely enriched for marker genes, but may represent a coordinated transcriptional state driven by a distinct regulatory logic.

This shift from descriptive expression mapping to putative regulatory architecture is valuable because it moves the study closer to mechanism. Spatial transcriptomic analyses often excel at showing where genes are expressed, but the biological question of greatest importance is often why a given region adopts a particular state. By identifying candidate master regulators, the present study offers a framework for understanding how the invasive niche may be stabilized and propagated. This is especially relevant in colorectal cancer, where boundary-associated phenotypes such as tumor budding, stromal infiltration, and metastasis likely depend on sustained regulatory programs rather than transient fluctuations in a few downstream genes. In this sense, the regulatory analysis adds explanatory depth to the co-expression and ligand-receptor findings by suggesting that interface-derived signals may converge on transcription factor networks that consolidate invasive identity.

At the same time, these findings should be interpreted with measured caution. Transcriptome-based inference of transcription factor activity is a strong hypothesis-generating approach, but it cannot substitute fully for direct functional validation. Transcription factor abundance does not always correspond to nuclear activity, and many regulatory events depend on chromatin

accessibility, phosphorylation, or cofactor availability. Therefore, the proposed regulators should be viewed as highly plausible candidates rather than definitive drivers. Even so, the value of this analysis is considerable. It defines a focused shortlist for follow-up studies using orthogonal methods such as spatial proteomics, multiplex immunofluorescence, chromatin assays, or perturbation models. In particular, any functional validation should preserve or recreate the tumor-stroma interface, because the data suggest that these regulatory programs are spatially induced rather than universally active across the tumor.

7. Spatially variable genes and co-expression modules offer a more systems-level view of tumor organization

The identification of thousands of spatially variable genes and their assembly into spatially coherent co-expression modules represents an important systems-level contribution. In complex tissues, single-gene patterns can be informative, but they rarely capture the full logic of biological states such as invasion, stromal activation, immune modulation, or vascular adaptation. Co-expression modules are therefore particularly useful because they represent coordinated programs rather than isolated markers. In the setting of spatial transcriptomics, this becomes even more meaningful: genes are not only co-expressed, but co-expressed in defined physical locations. Thus, module analysis can reveal how tissue regions are organized around integrated functional programs rather than scattered transcriptomic features.

This approach is well aligned with the broader development of computational methods for spatial gene pattern analysis. Statistical frameworks such as SPARK and SPARK-X were developed to identify spatial expression patterns robustly and at scale in spatial transcriptomic datasets, enabling researchers to distinguish genes whose expression is truly structured by position from those varying stochastically or by sampling noise (Sun et al., 2020; Zhu et al., 2021). The present study benefits conceptually from that analytical tradition because its biological claims about regional specialization depend on robust identification of genes that vary meaningfully across space. By then organizing those genes into modules, the study generates a more interpretable map of coordinated tissue biology.

This systems-level structure is especially relevant in colorectal cancer, where global molecular classifications have long been useful but often fail to explain the intratumoral coexistence of divergent states. A tumor classified overall as one molecular subtype may still contain localized domains that express stromal, immune, or mesenchymal programs in a highly regional manner. That possibility has already been suggested by work exploring the spatial heterogeneity of colorectal cancer consensus molecular subtype patterns (Guinney et al., 2015). The present study extends that idea by showing that regional modules can be recovered directly from intact tissue and related to specific anatomical compartments. In practical terms, this means that future biomarker strategies may benefit from module-level spatial readouts rather than relying exclusively on global subtype assignments. The more that colorectal tumors are shown to behave as composites of local ecological programs, the more valuable this kind of modular spatial analysis will become.

8. Cross-patient spatial programs suggest that regional tumor biology may be clinically generalizable

One common limitation of highly resolved spatial atlases is that they can become deeply descriptive without demonstrating whether the observed patterns generalize across patients. In that context, the cross-patient integration performed in this study is particularly valuable. By extracting recurrent spatial gene-expression programs across multiple colorectal cancer cases, the authors take an important step from single-sample cartography toward clinically relevant generalization. This matters because colorectal cancer is a highly heterogeneous disease, with substantial variation in stage, stromal content, immune composition, molecular subtype, and anatomical sampling. If spatial programs can nonetheless be recovered across patients, then they

are more likely to reflect genuine disease principles rather than idiosyncratic features of individual specimens.

This direction is consistent with previous efforts to bridge spatial heterogeneity and clinically meaningful classification in colorectal cancer. Molecular subtype frameworks provided a major advance in understanding disease diversity, but by definition they were derived from bulk transcriptomic profiles and do not specify how subtype-associated programs are distributed within the tissue (Guinney et al., 2015). More recent spatial work has suggested that subtype-related signals may be regionally distributed and that different portions of the same tumor can align with distinct biological states (Peng et al., 2022; Wang et al., 2023). The present study builds on those observations by identifying recurrent spatial programs that also appear to correlate with stage and survival-related variables, thereby hinting at possible prognostic utility.

If validated in larger cohorts, such spatial programs could become the basis of a new class of biomarkers. Rather than asking whether a tumor is globally immune-rich, stromal-rich, or mesenchymal-like, one could ask whether it contains a specific high-risk architectural pattern, such as a fibroblast-driven invasive boundary coupled to immune exclusion and EMT activation. This would likely be more biologically meaningful than whole-tumor averages because it reflects the microanatomical configuration where progression actually occurs. The challenge moving forward will be to test the reproducibility of these spatial programs across broader patient populations, different specimen types, and clinically annotated treatment cohorts. Nonetheless, the present study provides a persuasive proof of principle that subcellular-resolution spatial transcriptomics can identify cross-patient tissue programs with potential clinical importance.

9. Methodological strengths are substantial, but interpretation still requires caution

A notable strength of the study is its use of an integrated computational framework rather than reliance on a single analytical method. High-resolution spatial transcriptomics generates exceptionally rich data, but this richness also makes results sensitive to choices in segmentation, clustering, normalization, neighborhood construction, and statistical testing. By combining multiple analytical layers—spatial domain detection, cell-type deconvolution, ligand-receptor inference, regulatory network analysis, and cross-sample integration—the present study reduces the risk that its central conclusions are artifacts of any one computational decision. This integrative strategy is well aligned with the current maturation of the spatial transcriptomics field, where technical innovation is increasingly accompanied by equally important advances in analytical rigor (Yu et al., 2022).

However, several caveats remain important. First, spatial proximity does not automatically prove functional interaction. Ligand-receptor inference can identify biologically plausible communication routes, but actual signaling depends on receptor availability, post-translational regulation, ligand processing, diffusion constraints, and downstream intracellular competence. Second, even with high resolution, segmentation of densely packed tumor regions remains challenging, especially where nuclei overlap or cells have irregular morphologies. Misassignment of transcripts to neighboring cells can influence downstream interpretation of cell-type-specific programs and interaction networks. Third, the inference of regulatory networks from transcript abundance, while informative, does not directly measure chromatin occupancy or transcription factor activation state. These limitations are not unique to this study, but they are important reminders that spatial transcriptomics is most powerful when integrated with orthogonal validation strategies.

Another issue is the balance between discovery and overinterpretation. The higher the spatial resolution, the easier it becomes to detect narrow regional differences. Yet not every localized pattern will translate into stable biology or clinical relevance. Some gradients may reflect transient physiological states, local ischemia, sampling variation, or technical effects rather than core tumor mechanisms. Therefore, the strongest conclusions in this study are those supported by

convergence across multiple layers of evidence: domain structure, co-expression programs, signaling inference, and regulatory analysis. That convergence is indeed present for the invasive margin and tumor-stroma interface findings, which strengthens confidence in their biological significance. Still, future studies should validate these patterns in independent cohorts and with additional modalities before they are elevated to definitive disease mechanisms or clinical biomarkers.

10. Clinical and biological implications: toward spatially informed precision oncology in colorectal cancer

Taken together, the findings of this study support a broader conceptual shift in how colorectal cancer should be understood. The tumor microenvironment is not simply a background context for malignant cells; it is an organized, spatially structured system that actively shapes disease behavior. The invasive margin emerges as a privileged zone of plasticity, the tumor-stroma boundary functions as a signaling hub, immune niches are territorially organized, and transcriptional regulation appears to be compartment-specific. These insights argue that colorectal tumor biology cannot be fully captured by approaches that ignore tissue geography. Instead, the most clinically consequential processes appear to arise at microanatomical interfaces where local cell neighborhoods generate distinct molecular conditions.

This has clear implications for biomarker development. Current diagnostic and prognostic models in colorectal cancer still rely heavily on histopathology, stage, and bulk molecular data. While these remain indispensable, the present study suggests that spatially resolved biomarkers may offer a more direct link to disease mechanism. For example, a tumor characterized by a strongly activated fibroblast-rich invasive boundary and localized EMT program may have a very different risk profile from one with diffuse stromal content but no structured invasive niche. Likewise, immune biomarkers may become more informative if they capture whether lymphoid and effector populations actually access malignant compartments or remain segregated behind stromal barriers. In this sense, spatial transcriptomics could eventually complement conventional pathology by adding quantitative molecular information to the architecture already recognized under the microscope.

The translational horizon is therefore promising. As technologies such as Stereo-seq continue to mature and as clinical specimen compatibility improves, spatial profiling may help identify new therapeutic targets, refine patient stratification, and guide rational combination treatment strategies. Previous colorectal studies in primary, metastatic, and treatment-exposed settings have already shown that stromal and immune interactions are highly context dependent and spatially dynamic (Peng et al., 2022; Qin et al., 2023; Wang et al., 2023). The present study advances that field by providing a high-resolution atlas and an integrative interpretation of how these interactions are organized within intact tissue. Overall, it supports the view that future precision oncology in colorectal cancer will benefit not only from knowing which genes are expressed, but also from understanding exactly where those genes are expressed, which cells are adjacent, and which interfaces are driving progression.

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