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## CONTENTS

## PEDAGOGY

<b>Aitimbaev A., Issayev M., Apendiyev T.</b> Scientific and methodological opportunities for using archival materials in teaching the history of Kazakhstan in higher education institutions.....	19
<b>Akhmetova G., Kabdusheva A., Mussina A.</b> A quantitative study on university students' academic writing challenges and learning needs.....	40
<b>Akhmetova Zh.A., Nurgali S., Nurmetova D.</b> Pedagogical foundations of using digital resources in teaching academic writing.....	57
<b>Bekbolat Zh., Zholmakhanova A., Yildirim S.</b> Theoretical foundations of teaching M. Shokai's letters through a research-based approach.....	72
<b>Berdenkulova A.Zh., Zhandavletova R.B., Nazarova G.A.</b> A pedagogical model for improving educational quality through the "comfortable school - society - university" partnership.....	88
<b>Duisenova G., Shyndaliyev N., Shadiev R.</b> Comparative analysis of traditional and virtualized programming education.....	104
<b>Yeskendirova A., Kassenova N., Nogoyev Y.</b> Comparative analysis of texts created by AI and texts developed using quantization technology.....	121
<b>Zhanysbekova Sh., Nurmakhanova Zh., Akasheva A.</b> Actual problems of the formation of pragmatic competence: research based on the results of content analysis.....	136
<b>Zulpykhar Zh.E., Kapanova D.E., Zhilmagambetova R.Z.</b> Modern resources and technologies as a foundation for the development of teachers' professional competencies.....	153
<b>Isaeva A., Ananyeva S.</b> Axiological interpretation of the Kazakhstan theme in the works of K. Paustovsky: methodological approaches to teaching at the university.....	172
<b>Kabzhalelov K.R., Korganbayeva Zh.K., Nurakhmetova A.R.</b> Developing critical thinking through modern chatbots in chemistry education.....	190
<b>Kazhenova Zh.S., Kydyralina L.M., Rakhmatullina Z.T.</b> Problems of developing students' engineering skills.....	208

<b>Kaldarova A., Vasquez M., Kulgildinova T.</b> Developing students' profession-oriented speaking skills through ChatGPT.....	229
<b>Kapbarova G.Sh., Gundogdu A., Baidalieva E.A.</b> History teaching methodology: theoretical and practical foundations of the competency-based approach.....	243
<b>Kozhakhanova L., Amirova A.</b> Prospects for developing media literacy among primary school students.....	260
<b>Kuzhagulova G., Sydykova R., Smailova M</b> Features of education of national values in visually impaired students through Kazakh lyric songs.....	278
<b>Markhmadova Zh.K., Kassymova G.K., Okenova B.</b> Pedagogical aspects of developing and assessing the digital competence of pedagogy-psychologists.....	297
<b>Mateyeva M., Yeralin K., Burkitbaev T.</b> Training future teachers of artistic work for art-historical regional studies.....	318
<b>Makhanov N., Nishanova K.</b> Development of students' cognitive competencies through museum-based education: evidence from South Kazakhstan.....	333
<b>Myrzagereikyzy G., Yermekova Zh.K., Aldzhambekova G.T.</b> The use of action research in preparing future physics teachers for the development of functional literacy of students.....	348
<b>Reginbayeva N., Nametkulova F.</b> Methodological foundations of professionally-oriented physics education based on STEM education for future air transport specialists.....	365
<b>Serikbayeva N., Orynbekova A., Tuyakova U.</b> Methodology for developing digital competence of educational psychologists in modern education.....	385
<b>Toiganbekova M.E., Kazhigalieva G.A.</b> Aspects of creation and specification of educational texts for increasing the effectiveness of training.....	409
<b>Shegebayeva G., Zhumasheva T., Nurbekova S.</b> Prerequisites for the preparation of future educators for the creation of a health-educational environment based on nutriscology.....	422
<b>Shishov S.E., Iovbak A.S., Verko Y.A.</b> Integrated modular physics experiment as a means of organizing students' experimental activities in secondary school.....	443

## ECONOMICS

<b>Abdimoldayeva A., Madysheva A., Zhunussova G.</b> Transformation of logistics cost accounting in the agro-industrial complex under digitalization.....	461
<b>Abuova Zh., Duiskenova R., Kadyrbekova D.</b> The concept of sustainable development of the hotel business based on digital transformation and environmental management.....	479
<b>Amantay Mukhit, Kanabekova M., Oralbayeva Zh.</b> Digitalization as a driver of Kazakhstan’s economic growth: econometric analysis and structural effects.....	494
<b>Ashim N., Dzhrayova K., Kushenova M.</b> Improving the management of agricultural subsidies: Kyzylorda region.....	511
<b>Assemova R., Abdibekov S., Aitbayeva D.</b> Energy efficiency and innovation in agriculture: empirical evidence from Southern Kazakhstan.....	535
<b>Assanova Zh., Baimukhanova S., Konysbaeva G.</b> Environmental accounting, ESG reporting and digitalization: impact on cost reduction and sustainable development.....	554
<b>Baigelova A., Sadykova Zh., Epanchintseva S.</b> Industrial economy transformation in Kazakhstan: structural shifts, digitalization and productivity growth.....	571
<b>Beisekova Zh., Mutaliyeva A., Kunshigarova L.</b> Transformation of entrepreneurial activity in Kazakhstan in 2000–2025.....	590
<b>Beisenbayeva A., Kambarov B., Samenova N.</b> Development of small and medium-sized enterprises in Almaty: ecosystem factors and structural dynamics.....	611
<b>Bekisheva A., Beketova K., Dorohova N.</b> Human resource management practices and employee perceptions in Kazakhstan’s civil service.....	629
<b>Bissenbayeva S., Kireyeva A., Zhumaxanova K.</b> Digitalization, government support and innovation activity: evidence from regional analysis in Kazakhstan.....	646
<b>Em O.L., Kim D.</b> Features of risk management in collective investment.....	665

<b>Ibrayeva A., Kenesheva G., Arynova Zh.</b> Qualification mismatch in the labour market of an industrial region: a conceptual model and measurement mechanism.....	684
<b>Juman J., Mukhtarova K.S., Liao Z.</b> The modern model of China's economic cooperation with Central Asian countries.....	701
<b>Karakulova A., Bakirbekova A., Zhangirova R.</b> Improving the efficiency of digital transformation of agricultural enterprises: an empirical analysis of Kostanay region.....	718
<b>Kuralbayeva A.Sh., Issayeva G.K., Zhussipova E.E.</b> Energy-saving technologies in irrigated agriculture of Southern Kazakhstan: economic and environmental effects.....	734
<b>Naimanova Zh., Bakirbekova A., Kuralbayeva R.</b> Digital inequality and agricultural productivity: evidence from Southern Kazakhstan....	749
<b>Nartbayeva A., Dadabayeva D., Altuntas G.</b> Economic resilience of single-industry towns in Kazakhstan: a dynamic analysis of socio-economic indicators.....	767
<b>Nurlanuly A., Petrovčíková K., Shalbolova U.Zh.</b> Comparative analysis of aviation market development models in Kazakhstan and Slovakia.....	785
<b>Nyshanbayeva U., Moldashbayeva L., Urazbayeva Z.</b> Accounting and valuation of investment projects in digital tourism: an integrated approach.....	801
<b>Shegir G., Kerimova U., Kabi Sh.</b> The transition of the agro-industrial complex of the Almaty region to the production of value-added products.....	819
<b>Shiganbayeva N., Razakova D., Orlowska R.</b> Trade turnover between China and Kazakhstan in the context of contemporary analytical studies: factors, challenges, and risks.....	840
<b>Tuzubekova M., Zhunusova A., Kadirova N.</b> Analysis of SME support incentives in the manufacturing industry of the Republic of Kazakhstan.....	857
<b>Yeraliyeva Ya., Ruziyeva E., Alimbekova B.</b> Trend and structure of research on digital financial literacy: bibliometric approach.....	877
<b>Zhassan G., Taibek Zh., Imanova G.</b> Climate risk management in the banking sector: ESG-based global and Kazakhstani experience.....	891

## МАЗМҰНЫ

### ПЕДАГОГИКА

<b>Айтимбаев А.Т., Исаев М.С., Апендиев Т.А.</b> Қазақстан тарихын жоғары оқу орындарында оқытуда архив материалдарын пайдаланудың ғылыми-әдістемелік мүмкіндіктері (1920–1950 жж. Оңтүстік Қазақстандағы саяси қуғын-сүргін құрбандары тағдырлары негізінде).....	19
<b>Ахметова Г.С., Кабдушева А.Б., Мусина А.Б.</b> Университет студенттерінің академиялық жазылымдағы қиындықтары мен оқу қажеттіліктеріне арналған сандық зерттеу.....	40
<b>Ахметова Ж.А., Нұрғали С., Нурметова Д.</b> Академиялық жазуды оқытуда сандық ресурстарды пайдаланудың педагогикалық негіздері.....	57
<b>Бекболат Ж.Н., Жолмаханова А.Б., Сейфуллах Йылдырым</b> Мұстафа Шоқай хаттарын зерттеушілік әдіс арқылы оқытудың теориялық негіздері.....	72
<b>Берденкулова А.Ж., Жандавлетова Р.Б., Назарова Г.А.</b> «Жайлы мектеп – қоғам – университет» серіктестігі негізінде білім сапасын арттырудың педагогикалық моделі.....	88
<b>Ескендірова А.А., Касенова Н.Б., Ногоев Ю.Я.</b> ЖИ арқылы жасалған мәтіндер мен кванттау технологиясы арқылы әзірленген мәтіндердің салыстырмалы талдауы.....	104
<b>Жанысбекова Ш., Нурмаханова Ж., Акашева Ә.</b> Прагматикалық құзіреттілікті қалыптастырудың өзекті мәселелері: контент-анализ нәтижелері бойынша зерттеу.....	121
<b>Дүйсенова Г.А., Шындалиев Н.Т., Шадиев Р.Н.</b> Дәстүрлі және виртуалды бағдарламалау білімінің салыстырмалы талдауы.....	136
<b>Зулпыхар Ж.Е., Капанова Д.Е., Жилмагамбетова Р.З.</b> Педагогтердің кәсіби құзыреттілігін дамытудың негізі ретінде қазіргі заманғы ресурстар мен технологиялар.....	153
<b>Исаева А.А., Ананьева С.В.</b> К. Паустовский шығармашылығындағы Қазақстан тақырыбының аксиологиялық интерпретациясы: жоғары оқу орнында оқытудың әдіснамалық тәсілдері.....	172
<b>Кабжалелов К.Р., Қорғанбаева Ж.Қ., Нурахметова А.Р.</b> Химияны оқыту барысында заманауи чат-боттар арқылы сыни ойлауды дамыту.....	190

<b>Каженова Ж.С., Қыдыралина Л.М., Рахматулина З.Т.</b> Оқушылардың инженерлік дағдыларын дамыту мәселелері.....	208
<b>Калдарова А.К., Васкес М.А., Кульгильдинова Т.А.</b> Студенттердің кәсіби-бағдарланған айтылым дағдыларын ChatGPT арқылы дамыту.....	229
<b>Капбарова Г.Ш., Гюндогду А., Байдалиева Э.А.</b> Тарихты оқыту әдістемесі: құзыреттілікке негізделген тәсілді қолданудың теориялық және практикалық негіздері.....	243
<b>Кожыханова Л., Амирова А.</b> Бастауыш сынып оқушыларының медиасауаттылығын дамыту перспективалары.....	260
<b>Кужагулова Г.Е., Сыдыкова Р.Ш., Смаилова М.С.</b> Көру қабілеті бұзылған білім алушыларды қазақтың лирикалық әндері арқылы ұлттық құндылықтарға тәрбиелеудің ерекшеліктері.....	278
<b>Мархмадова Ж.Қ., Касымова Г.К., Өкенова Б.</b> Педагог-психологтың цифрлық құзыреттілігін қалыптастыру және бағалаудың педагогикалық аспектілері.....	297
<b>Матеева М.А., Ералин Қ., Буркитбаев Т.</b> Болашақ көркем еңбек мұғалімдерін өнертанымдық өлкетануға даярлау.....	318
<b>Маханов Н., Нишанова К.</b> Музейлік білім беру негізінде оқушылардың танымдық құзыреттіліктерін дамыту (Оңтүстік Қазақстан мысалында).....	333
<b>Мырзагерейқызы Г., Еркекова Ж.К., Алджамбекова Г.Т.</b> Болашақ физика мұғалімдерін оқушылардың функционалдық сауаттылығын дамытуға даярлауда action research пайдалану.....	348
<b>Регинбаева Н.А., Наметкулова Ф.Д.</b> Болашақ әуе транспорты мамандарына физиканы STEM білім беру негізінде кәсіби-бағдарлы оқытудың әдістемелік негіздері.....	365
<b>Серикбаева Н.Б., Орынбекова А.С., Туякова У.Ж.</b> Қазіргі білім беруде педагог-психологтардың цифрлық құзыреттілігін дамыту әдістемесі.....	385
<b>Тойғанбекова М.Е., Қажығалиева Г.А.</b> Оқытудың тиімділігін арттыру үшін оқу мәтіндерін құру және нақтылау аспектілері.....	409

**Шегебаева Г.У., Жумашева Т.С., Нурбекова С.М.**

Болашақ тәрбиешілерді нутрициология негізінде денсаулық сақтау-білім беру ортасын құруға дайындаудың алғышарттары.....422

**Шишов С.Е., Иовбак А.С., Верко Е.А.**

Орта мектепте оқушылардың эксперименталдық қызметін ұйымдастыру құралы ретінде интеграцияланған модульді физика эксперименті.....443

**ЭКОНОМИКА****Абдимолдаева А., Мадышева А., Жунусова Г.**

Цифрландыру жағдайында агроөнеркәсіптік кешендегі логистикалық шығындар есебін қайта құру.....461

**Абуова Ж., Дүйсеннова Р., Кадырбекова Д.**

Цифрлық трансформация және экологиялық басқару негізіндегі қонақ үй бизнесінің тұрақты даму тұжырымдамасы.....479

**Әшім Н., Джрауова К., Кушенова М.**

Ауылшаруашылығы субсидияларын басқаруды жетілдіру: Қызылорда облысы...494.

**Мұхит Амантай, Кенабекова М., Оралбаева Ж.**

Цифрландыру Қазақстанның экономикалық өсуінің драйвері ретінде: эконометрикалық талдау және құрылымдық әсерлер.....511

**Асемова Р., Абдибеков С., Айтбаева Д.**

Ауылшаруашылығындағы энергия тиімділігі және инновациялар: Оңтүстік Қазақстан бойынша эмпирикалық дәлелдер.....535

**Асанова Ж., Баймуханова С., Қонысбаева Г.**

Экологиялық есеп, ESG-есептілік және цифрландыру: шығындарды төмендетуге және орнықты дамуға әсері.....554

**Байгелова А., Садыкова Ж., Епанчинцева С.**

Қазақстандағы өнеркәсіп экономикасының трансформациясы: құрылымдық өзгерістер, цифрландыру және өнімділіктің өсуі.....571

**Бейсекова Ж., Муталиева А., Куншигарова Л.**

2000–2025 жылдары Қазақстандағы кәсіпкерлік қызметтің трансформациясы.....590

**Бейсенбаева А., Қамбаров Б., Саменова Н.**

Алматыда шағын және орта кәсіпкерлікті дамыту: экожүйелік факторлар және құрылымдық динамика.....611

**Бекишева А., Бекетова К., Дорохова Н.**

Қазақстанның мемлекеттік қызметіндегі адам ресурстарын басқару тәжірибелері және қызметкерлердің қабылдауы.....629

**Бисенбаева С., Киреева А., Жұмаксанова К.**

Цифрландыру, мемлекеттік қолдау және инновациялық белсенділік:  
Қазақстан өңірлерінің талдауы.....646

**Эм О.Л., Ким Д.**

Ұжымдық инвестициялардағы тәуекелдерді басқарудың ерекшеліктері.....665

**Ибраева А., Кенешева Г., Арынова Ж.**

Өнеркәсіптік өңірдің еңбек нарығындағы біліктілік сәйкессіздігі:  
тұжырымдамалық модель және өлшеу тетігі.....684

**Жұман Ж., Мұхтарова К.С., Ляо Чжан**

Қытайдың Орталық Азия елдерімен экономикалық ынтымақтастығының  
заманауи моделі.....701

**Қаракұлова А., Бакирбекова А., Жангирова Р.**

Ауыл шаруашылығы кәсіпорындарының цифрлық трансформациясының  
тиімділігін арттыру: Қостанай облысының эмпирикалық талдауы.....718

**Құралбаева А.Ш., Исаева Г.К., Жусипова Э.Е.**

Оңтүстік Қазақстанның суармалы ауыл шаруашылығындағы энергия үнемдеу  
технологиялары: экономикалық және экологиялық тиімділік.....734

**Найманова Ж., Бакирбекова А., Құралбаева Р.**

Цифрлық теңсіздік және ауыл шаруашылығының өнімділігі:  
Оңтүстік Қазақстан деректері.....749

**Нартбаева А., Дадабаева Д., Алтунташ Г.**

Қазақстан моноқалаларының экономикалық резиленттілігі: әлеуметтік-  
экономикалық көрсеткіштердің динамикалық талдауы.....767

**Нұрланұлы А., Петровчикова К., Шалболова У.Ж.**

Қазақстан мен Словакияның авиациялық нарықтарының даму модельдерін  
салыстырмалы талдау.....785

**Нышанбаева Ұ., Молдашбаева Л., Уразбаева З.**

Цифрлық туризмдегі инвестициялық жобаларды есепке алу және бағалау:  
интеграцияланған тәсіл.....801

**Шегір Г., Керимова У., Қаби Ш.**

Алматы облысының агроөнеркәсіптік кешенінің қосылған құны бар өнім  
өндіруге көшуі.....819

**Шиганбаева Н., Разакова Д., Орловска Р.**

Қытай мен Қазақстан арасындағы тауар айналымы: факторлар, мәселелер  
және тәуекелдер.....840

**Тузубекова М., Жунусова А., Кадирова Н.**

Қазақстан Республикасының өңдеу өнеркәсібіндегі шағын және орта бизнесті  
ынталандыруды талдау.....857

**Ералиева Я., Рузиева Э., Алимбекова Б.**

Цифрлық қаржылық сауаттылық бойынша зерттеулердің тенденциялары  
мен құрылымы: библиометриялық тәсіл.....877

**Жасан Г.Ж., Тайбек Ж.Қ., Иманова Г.А.**

Банк секторындағы климаттық тәуекелдерді басқару: ESG негізіндегі әлемдік  
және қазақстандық тәжірибе.....891

## СОДЕРЖАНИЕ

## ПЕДАГОГИКА

**Айтимбаев А.Т., Исаев М.С., Апендиев Т.А.**

Научно-методические возможности использования архивных материалов при преподавании истории Казахстана в высших учебных заведениях (на примере судеб жертв политических репрессий в Южном Казахстане в 1920–1950 гг.).....19

**Ахметова Г.С., Кабдушева А.Б., Мусина А.Б.**

Количественное исследование проблем академического письма и образовательных потребностей студентов университета.....40

**Ахметова Ж.А., Нурғали С., Нурметова Д.**

Педагогические основы использования цифровых ресурсов в обучении академическому письму.....57

**Бекболат Ж.Н., Жолмаханова А.Б., Сейфуллах Йылдырым**

Теоретические основы обучения письмам М. Шокая исследовательским методом.....72

**Берденкулова А.Ж., Жандавлетова Р.Б., Назарова Г.А.**

Педагогическая модель повышения качества образования на основе партнёрства «комфортная школа – общество – университет».....88

**Дуйсенова Г.А., Шындалиев Н.Т., Шадиев Р.Н.**

Сравнительный анализ традиционного и виртуализированного обучения программированию.....104

**Ескенди́рова А.А., Касенова Н.Б., Ногоев Ю.Я.**

Сравнительный анализ текстов, созданных ИИ и текстов, разработанных с помощью технологии квантования.....121

**Жанысбекова Ш., Нурмаханова Ж., Акашева А.**

Актуальные проблемы формирования прагматической компетенции: исследование по результатам контент-анализа.....136

**Зулпыхар Ж.Е., Капанова Д.Е., Жилмагамбетова Р.З.**

Современные ресурсы и технологии как основа развития профессиональных компетенций педагогов.....153

**Исаева А.А., Ананьева С.В.**

Аксиологическая интерпретация казахстанской тематики в творчестве К. Паустовского: методологические подходы к преподаванию в вузе.....172

<b>Кабжалелов К.Р., Корганбаева Ж.К., Нурахметова А.Р.</b> Развитие критического мышления с помощью современных чат-ботов при обучении химии.....	190
<b>Каженова Ж.С., Кыдыралина Л.М., Рахматуллина З.Т.</b> Проблемы развития инженерных навыков учащихся.....	208
<b>Калдарова А.К., Васкез М.А., Кульгильдинова Т.А.</b> Развитие профессионально ориентированных навыков устной речи студентов с использованием ChatGPT.....	229
<b>Капбарова Г.Ш., Гюндогду А., Байдалиева Э.А.</b> Методика преподавания истории: теоретические и практические основы применения компетентностного подхода.....	243
<b>Кожуханова Л., Амирова А.</b> Перспективы развития медиаграмотности среди учащихся начальной школы.....	260
<b>Кужагулова Г.Е., Сыдыкова Р.Ш., Смаилова М.С.</b> Особенности воспитания национальных ценностей у слабовидящих обучающихся через казахские лирические песни.....	278
<b>Мархмадова Ж.К., Касымова Г.К., Окенова Б.</b> Педагогические аспекты формирования и оценки цифровой компетентности педагогов-психологов.....	297
<b>Матеева М.А., Ералин К., Буркитбаев Т.</b> Подготовка будущих учителей художественного труда к искусствоведческому краеведению.....	318
<b>Маханов Н., Нишанова К.</b> Развитие познавательных компетенций учащихся на основе музейного образования (на примере Южного Казахстана).....	333
<b>Мырзагерейкызы Г., Еркекова Ж.К., Алджамбекова Г.Т.</b> Использование action research в подготовке будущих учителей физики к развитию функциональной грамотности учащихся.....	348
<b>Регинбаева Н.А., Наметкулова Ф.Д.</b> Методические основы профессионально-ориентированного обучения физике на основе STEM образования для будущих специалистов воздушного транспорта.....	365
<b>Серикбаева Н.Б., Орынбекова А.С., Туякова У.Ж.</b> Методика развития цифровой компетентности педагогов-психологов в современном образовании.....	385

**Тойганбекова М.Е., Кажигалиева Г.А.**

Аспекты создания и спецификации учебных текстов для повышения эффективности обучения.....409

**Шегебаева Г.У., Жумашева Т.С., Нурбекова С.М.**

Предпосылки подготовки будущих воспитателей к созданию здоровьесберегающей образовательной среды на основе нутрициологии.....422

**Шишов С.Е., Иовбак А.С., Верко Е.А.**

Интегрированный модульный физический эксперимент как средство организации экспериментальной деятельности учащихся в средней школе.....443

**ЭКОНОМИКА****Абдимолдаева А., Мадышева А., Жунусова Г.**

Трансформация учета логистических затрат в агропромышленном комплексе в условиях цифровизации.....461

**Абуова Ж., Дуйскенова Р., Кадырбекова Д.**

Концепция устойчивого развития гостиничного бизнеса на основе цифровой трансформации и экологического менеджмента.....479

**Ашим Н., Джрауова К., Кушенова М.**

Совершенствование управления агросубсидиями: Кызылординская область.....494

**Мухит Амантай, Канабекова М., Оралбаева Ж.**

Цифровизация как драйвер экономического роста Казахстана: эконометрический анализ и структурные эффекты.....511

**Асемова Р., Абдибеков С., Айтбаева Д.**

Энергоэффективность и инновации в сельском хозяйстве: эмпирические данные Южного Казахстана.....535

**Асанова Ж., Баймуханова С., Конысбаева Г.**

Экологический учет, ESG-отчетность и цифровизация: влияние на снижение издержек и устойчивое развитие.....554

**Байгелова А., Садыкова Ж., Епанчинцева С.**

Трансформация промышленной экономики Казахстана: структурные сдвиги, цифровизация и рост производительности.....571

**Бейсекова Ж., Муталиева А., Куншигарова Л.**

Трансформация предпринимательской деятельности в Казахстане в 2000–2025 годах.....590

<b>Бейсенбаева А., Камбаров Б., Саменова Н.</b> Развитие малого и среднего предпринимательства в Алматы: экосистемные факторы и структурная динамика.....	611
<b>Бекишева А., Бекетова К., Дорохова Н.</b> Практики управления человеческими ресурсами и восприятие сотрудников в государственной службе Казахстана.....	629
<b>Бисенбаева С., Киреева А., Жумаксанова К.</b> Цифровизация, государственная поддержка и инновационная активность: региональный анализ Казахстана.....	646
<b>Эм О.Л., Ким Д.</b> Особенности управления рисками в сфере коллективных инвестиций.....	665
<b>Ибраева А., Кенешева Г., Арынова Ж.</b> Несоответствие квалификации на рынке труда промышленного региона: концептуальная модель и механизм измерения.....	684
<b>Жуман Ж., Мухтарова К.С., Ляо Чжан</b> Современная модель экономического сотрудничества Китая со странами Центральной Азии.....	701
<b>Каракулова А., Бакирбекова А., Жангирова Р.</b> Повышение эффективности цифровой трансформации сельскохозяйственных предприятий: эмпирический анализ Костанайской области.....	718
<b>Куралбаева А.Ш., Исаева Г.К., Жусипова Э.Е.</b> Энергосберегающие технологии в орошаемом сельском хозяйстве Южного Казахстана: экономические и экологические эффекты.....	734
<b>Найманова Ж., Бакирбекова А., Куралбаева Р.</b> Цифровое неравенство и продуктивность сельского хозяйства: данные из Южного Казахстана.....	749
<b>Нартбаева А., Дадабаева Д., Алтунташ Г.</b> Экономическая резилиентность моногородов Казахстана: динамический анализ социально-экономических показателей.....	767
<b>Нурланулы А., Петровчикова К., Шалболова У.Ж.</b> Сравнительный анализ моделей развития авиационных рынков Казахстана и Словакии.....	785
<b>Нышанбаева У., Молдашбаева Л., Уразбаева З.</b> Учет и оценка инвестиционных проектов в цифровом туризме: интегрированный подход.....	801

**Шегир Г., Керимова У., Каби Ш.**

Переход агропромышленного комплекса Алматинской области к производству продукции с добавленной стоимостью.....819

**Шиганбаева Н., Разакова Д., Орловска Р.**

Товарооборот Китая и Казахстана: факторы, проблемы и риски.....840

**Тузубекова М., Жунусова А., Кадилова Н.**

Анализ стимулирования малого и среднего бизнеса в обрабатывающей промышленности Республики Казахстан.....857

**Ералиева Я., Рузиева Э., Алимбекова Б.**

Тенденции и структура исследований цифровой финансовой грамотности: библиометрический подход.....877

**Жасан Г.Ж., Тайбек Ж.Қ., Иманова Г.А.**

Управление климатическими рисками в банковском секторе: стандарты ESG в мировом и казахстанском опыте.....891

# ЭКОНОМИКА – ЭКОНОМИКА – ECONOMICS

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## TRANSFORMATION OF LOGISTICS COST ACCOUNTING IN THE AGRO-INDUSTRIAL COMPLEX UNDER DIGITALIZATION

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**Abstract.** In the context of the accelerating digital transformation of the agro-industrial complex (AIC), the importance of forming an effective logistics cost accounting system as a key cost management tool and ensuring the sustainable development of the industry is increasing. Logistics costs in the agro-industrial complex are characterized by a high share in the cost of production, significant variability and dependence on institutional and technological factors, which requires improved approaches to their accounting. The purpose of the study is to identify theoretical contradictions and practical limitations that hinder the formation of an adequate system for accounting for logistical costs in the context of digitalization, as well as to substantiate the directions of its transformation using digital technologies and artificial intelligence (AI) tools in the context of achieving the Sustainable Development Goals (SDGs). The methodological basis of the research consists of methods of systematic and comparative analysis, synthesis of theoretical

approaches to management accounting and logistics, as well as content analysis of the regulatory framework and statistical data of the Republic of Kazakhstan. The results of the study show that the existing logistics cost accounting systems in the agro-industrial complex are characterized by fragmentation, lack of a unified cost classification, low degree of digital integration and limited use of AI-based analytical tools. It has been found that these restrictions reduce the effectiveness of cost management and hinder the achievement of SDGs 2, 9, 12 and 13. The scientific novelty of the research lies in the development of a conceptual four-level model of a digital logistics cost accounting system based on the integration of IoT, ERP, blockchain and predictive analytics technologies. The practical significance of the work is determined by the possibility of applying the proposed model to increase the transparency of logistics processes, reduce losses and form sustainable agro-food systems.

**Keywords:** agro-industrial complex, logistics costs, cost accounting, digitalization, digital transformation, artificial intelligence, supply chain management

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## **ЦИФРЛАНДЫРУ ЖАҒДАЙЫНДА АГРОӨНЕРКӘСІПТІК КЕШЕНДЕГІ ЛОГИСТИКАЛЫҚ ШЫҒЫНДАР ЕСЕБІН ҚАЙТА ҚҰРУ**

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**Аннотация.** Агроөнеркәсіптік кешеннің (АӨК) жеделдетілген цифрлық трансформациясы жағдайында шығындарды басқарудың және саланың тұрақты дамуын қамтамасыз етудің негізгі құралы ретінде логистикалық шығындарды есепке алудың тиімді жүйесін қалыптастырудың маңыздылығы артып келеді. АӨК-дегі логистикалық шығындар өнімнің өзіндік құнының жоғары үлесімен, айтарлықтай өзгергіштігімен және институционалдық және

технологиялық факторларға тәуелділігімен сипатталады, бұл оларды есепке алу тәсілдерін жетілдіруді талап етеді. Зерттеудің мақсаты цифрландыру жағдайында логистикалық шығындарды есепке алудың барабар жүйесін қалыптастыруға кедергі келтіретін теориялық қайшылықтар мен практикалық шектеулерді анықтау, сондай-ақ тұрақты даму мақсаттарына (ТДМ) қол жеткізу контекстінде цифрлық технологиялар мен жасанды интеллект (АИ) құралдарын пайдалана отырып, оны трансформациялау бағыттарын негіздеу болып табылады. Зерттеудің әдіснамалық негізін жүйелі және салыстырмалы талдау әдістері, басқарушылық есеп пен логистикаға теориялық тәсілдердің синтезі, сондай-ақ Қазақстан Республикасының нормативтік-құқықтық базасы мен статистикалық деректерінің контент-талдауы құрайды. Зерттеу нәтижелері Агроөнеркәсіптік кешендегі логистикалық шығындарды есепке алудың қолданыстағы жүйелері фрагменттілікпен, шығындардың бірыңғай жіктелуінің болмауымен, цифрлық интеграцияның төмен деңгейімен және АИ негізіндегі аналитикалық құралдарды шектеулі қолданумен сипатталатынын көрсетеді. Бұл шектеулер шығындарды басқару тиімділігін төмендететіні және SDG 2, 9, 12 және 13-ке қол жеткізуге кедергі келтіретіні анықталды. Зерттеудің ғылыми жаңалығы IoT, ERP, блокчейн және болжамды аналитика технологияларын біріктіруге негізделген цифрлық логистикалық шығындарды есепке алу жүйесінің тұжырымдамалық төрт деңгейлі моделін жасау болып табылады. Жұмыстың практикалық маңыздылығы логистикалық процестердің ашықтығын арттыру, шығындарды азайту және тұрақты агроазық-түлік жүйелерін қалыптастыру үшін ұсынылған модельді қолдану мүмкіндігімен анықталады.

**Түйін сөздер:** агроөнеркәсіптік кешен, логистикалық шығындар, шығындар есебі, цифрландыру, цифрлық трансформация, жасанды интеллект, жеткізу тізбегін басқару

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## **ТРАНСФОРМАЦИЯ УЧЕТА ЛОГИСТИЧЕСКИХ ЗАТРАТ В АГРОПРОМЫШЛЕННОМ КОМПЛЕКСЕ В УСЛОВИЯХ ЦИФРОВИЗАЦИИ**

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**Аннотация.** В условиях ускоряющейся цифровой трансформации агропромышленного комплекса (АПК) возрастает значимость формирования эффективной системы учёта логистических издержек как ключевого инструмента управления затратами и обеспечения устойчивого развития отрасли. Логистические издержки в АПК характеризуются высокой долей в себестоимости продукции, значительной вариативностью и зависимостью от институциональных и технологических факторов, что требует совершенствования подходов к их учёту. Цель исследования заключается в выявлении теоретических противоречий и практических ограничений, препятствующих формированию адекватной системы учёта логистических издержек в условиях цифровизации, а также в обосновании направлений её трансформации с использованием цифровых технологий и инструментов искусственного интеллекта (ИИ) в контексте достижения Целей устойчивого развития (ЦУР). Методологическую основу исследования составляют методы системного и сравнительного анализа, синтез теоретических подходов к управленческому учёту и логистике, а также контент-анализ нормативно-правовой базы и статистических данных Республики Казахстан. Результаты исследования показывают, что существующие системы учёта логистических издержек в АПК характеризуются фрагментарностью, отсутствием унифицированной классификации затрат, низкой степенью цифровой интеграции и ограниченным применением аналитических инструментов на базе ИИ. Установлено, что данные ограничения снижают эффективность управления затратами и препятствуют достижению ЦУР 2, 9, 12 и 13. Научная новизна исследования заключается в разработке концептуальной четырёхуровневой модели цифровой системы учёта логистических издержек, основанной на интеграции технологий IoT, ERP, блокчейна и предиктивной аналитики. Практическая значимость работы определяется возможностью применения предложенной модели для повышения прозрачности логистических процессов, снижения потерь и формирования устойчивых агропродовольственных систем.

**Ключевые слова:** агропромышленный комплекс, логистические издержки, учет затрат, цифровизация, цифровая трансформация, искусственный интеллект, управление цепями поставок

**Introduction.** The agro-industrial complex (AIC) is a strategically important sector of the national economy that ensures food security, employment and sustainable development of the regions. At the same time, it is one of the most vulnerable industries due to its high dependence on natural and climatic conditions, the seasonal nature of production processes, the spatial dispersion of producers

and the complexity of agri-food supply chains (Bowersox et al., 2013). In these conditions, logistics acquires a system-forming role, acting as a key link between the stages of production, processing and distribution of products. Logistics costs form a significant share of total costs in agri-food chains, accounting for an estimated 15 to 30% of the cost of final products (Coyle et al., 2016). However, their actual level is often higher due to hidden losses associated with inefficient transportation, storage, and inventory management. This leads to the formation of a gap between the actual logistical costs and their reflection in the accounting system, which reduces the validity of management decisions and the effectiveness of resource allocation.

In the context of the digital transformation of the economy, traditional cost accounting methods show limited applicability. Classical approaches formed within the framework of the industrial production model do not take into account the multidimensionality, dynamism and high level of uncertainty of modern logistics processes (Kaplan and Anderson, 2007). As a result, existing accounting systems do not provide sufficient accuracy and timeliness of information on logistics costs, which limits the possibilities of their effective control and management. The relevance of the issue under consideration is growing in the context of the implementation of the UN 2030 Agenda for Sustainable Development. The inefficiency of logistics processes in agriculture is directly related to food losses, which, according to the FAO (2019), reach about one third of total production. This contradicts the key Sustainable Development Goals, first of all SDG 2 (“Zero hunger”) and SDG 12 (“Responsible consumption and production”). Consequently, improving the logistics cost accounting system becomes not only an economic, but also a socially significant task.

At the same time, the development of digital technologies - big data, artificial intelligence, the Internet of Things, blockchain and cloud platforms - opens up new opportunities for the transformation of logistics processes and cost accounting systems (Schwab, 2017). These technologies enable real-time data collection and processing, increase the transparency of supply chains, and improve the quality of management decisions. At the same time, the development of digital technologies - big data, artificial intelligence, the Internet of Things, blockchain and cloud platforms - opens up new opportunities for the transformation of logistics processes and cost accounting systems (Schwab, 2017). These technologies enable real-time data collection and processing, increase the transparency of supply chains, and improve the quality of management decisions. At the same time, their implementation is accompanied by a number of methodological challenges related to the classification of digital costs, the integration of heterogeneous data and ensuring comparability of accounting information.

Despite a significant amount of research on logistics digitalization and supply chain optimization, there remains a significant gap in the scientific literature related to the transformation of logistics cost accounting systems in the digital economy, Despite a significant amount of research on logistics digitalization and supply chain optimization, there remains a significant gap in the scientific literature related to

the transformation of logistics cost accounting systems in the digital economy, especially in the agro-industrial sector. Approaches to the integration of digital technologies into accounting systems, as well as to assessing their impact on the structure and dynamics of costs, have not been sufficiently developed.

In this regard, the purpose of this study is to identify theoretical and practical problems of forming a logistics cost accounting system in the agro-industrial complex in the context of digitalization and to develop conceptual approaches to their solution. To achieve this goal, the following tasks are being solved:

- analysis of the theoretical foundations of accounting for logistical costs;
- identification of systemic accounting problems in the context of digital transformation;
- assessment of the potential of digital technologies and artificial intelligence in cost management;
- Development of a conceptual model for digital accounting of logistics costs.

**Literature review.** The study of logistics costs was formed at the junction of management accounting, logistics and operational management, which predetermined its interdisciplinary nature. Most modern approaches are based on the Total Cost Concept, according to which logistics efficiency is determined not by minimizing individual cost elements, but by optimizing the entire system, taking into account the relationship between transportation, storage, inventory, and service level (Ballou, 2004; Bowersox et al., 2013). This approach laid the foundation for the interpretation of logistics costs as a complex category, including both direct and indirect costs incurred at various stages of product movement. At the same time, the classical structure of logistics costs, including transportation, warehousing, inventory maintenance and order processing costs (Coyle et al., 2016), is insufficient in modern conditions. Subsequent research shows that traditional models do not take into account hidden losses, transaction costs, as well as environmental and social effects accompanying logistics activities (Seuring and Müller, 2008). This is especially true for the agro-industrial complex, where a high proportion of product losses, infrastructural constraints and seasonal fluctuations significantly transform the actual cost structure.

Management accounting methods, primarily Activity-Based Costing (ABC), have made a significant contribution to the development of logistics cost accounting methodology, making it possible to more accurately allocate indirect costs by type of activity. Further development of this logic is reflected in the Time-Driven Activity-Based Costing (TDABC) model, focused on accounting for the time parameters of operations and resource utilization (Kaplan and Anderson, 2007). For logistics, these approaches are of particular importance because they allow us to take into account not only the fact of costs, but also their dependence on the intensity, duration and complexity of business processes, which brings accounting closer to the real economic nature of logistics operations.

The industry-specific nature of the agro-industrial complex significantly complicates the formation and accounting of logistical costs. The seasonality of

agricultural production leads to an uneven distribution of logistical flows and creates peak loads on infrastructure during harvest periods (Anikin and Rodkina, 2014). At the same time, the perishability of products increases the requirements for speed of delivery, compliance with temperature conditions and reliable storage, which leads to increased costs for cold chain logistics and specialized logistics. According to the FAO (2019), it is the stages of transportation and storage that account for a significant proportion of food losses, which makes logistics a critical factor in the efficiency of the agricultural sector.

An additional complicating factor is the spatial asymmetry of agricultural production: agricultural producers are usually geographically dispersed, while processing and sales markets are concentrated in a limited number of nodes. This increases the transport component of costs and increases the importance of logistics as a factor of product competitiveness. In the scientific literature, this problem is often interpreted through the concept of the “last kilometer”, which is particularly acute in the agricultural sector due to the remoteness of producers and infrastructural constraints (Kirillova, 2020). In addition, the multi-stage nature of agri-food supply chains, including producers, processors, logistics companies and retail chains, determines the inter-organizational nature of logistics costs. Under these conditions, traditional accounting systems focused on the level of an individual enterprise are insufficient because they do not allow tracking costs along the entire value chain (Christopher, 2016). This leads to the risks of double counting, information distortion and underestimation of real losses.

Of particular importance in the context of accounting for logistical costs is the problem of accounting for product losses. In traditional practice, such losses are often reflected in other expenses or natural losses, without linking them to the quality of logistics solutions. However, from an economic point of view, product losses are a form of logistical costs directly related to the inefficiency of storage and transportation processes. Their inclusion in the accounting system makes it possible to increase the completeness of information and strengthen the relationship between accounting and sustainable development objectives.

The current stage of logistics development is characterized by an active digital transformation associated with the introduction of Industry 4.0 technologies. In the scientific literature, logistics digitalization is considered as a transition from fragmented management models to integrated digital ecosystems based on the use of big data, the Internet of Things, artificial intelligence, blockchain and cloud platforms (Schwab, 2017; Tjahjono et al., 2017). These technologies provide a qualitatively new level of transparency, manageability and efficiency of logistics processes. Internet of Things technologies allow for continuous monitoring of logistics operations in real time, recording the parameters of product condition and transportation conditions (Atzori et al., 2010). Artificial intelligence enhances analysis and forecasting capabilities by providing route optimization, inventory management, and cost allocation (Acemoglu and Restrepo, 2020; Frank et al.,

2019). In turn, blockchain ensures the traceability of transactions and forms the basis for inter-organizational accounting of logistical costs (Tian, 2017).

Despite the significant potential of digitalization, the scientific literature highlights the significant limitations of its implementation in accounting for logistical costs. The key problem remains the lack of uniform approaches to classifying digital costs, which reduces data comparability and makes it difficult to assess the effectiveness of digital solutions. Additional difficulties are associated with the integration of heterogeneous data generated by various digital systems, as well as the need to ensure transparency and reproducibility of the algorithms used in calculations (Ivanov et al., 2019). An important area of modern research is the integration of logistical costs into the context of sustainable development and the ESG agenda. Within the framework of this approach, logistics cost management is considered not only as a tool to increase economic efficiency, but also as a mechanism to reduce food losses, increase resource efficiency and reduce environmental impact (Seuring and Müller, 2008). However, in the existing literature, accounting for logistics costs in agriculture is still insufficiently integrated with the approaches of sustainable logistics and non-financial reporting.

The analysis shows that despite a significant amount of research, a number of significant scientific gaps remain. Firstly, the methodological foundations for accounting for logistical costs have not been sufficiently developed, taking into account the industry specifics of the agro-industrial complex. Secondly, logistics digitalization and cost accounting are considered mostly separately, whereas their integration requires an integrated approach. Third, there is limited attention to the inclusion of hidden losses, digital costs and environmental effects in the accounting system. Fourth, the relationship between accounting for logistical costs and sustainable development goals and ESG metrics has been poorly studied. Thus, the relevance of this study is determined by the need to develop an integrated approach to the formation of a logistics cost accounting system in the agro-industrial complex in the context of digitalization. Unlike existing works, this study aims to integrate logistics, digital technologies, and management accounting into a single conceptual model focused on both improving economic efficiency and ensuring sustainable development.

**Materials and Methods.** The methodological basis of the research is based on an interdisciplinary approach that integrates the provisions of management accounting, logistics theory, supply chain management (SCM) concepts and the digital economy. Within the framework of this approach, accounting for logistical costs is considered as a complex socio-economic system formed under the influence of technological, institutional and organizational factors. This approach allows us to go beyond traditional cost accounting and consider logistics costs as a dynamic category reflecting the interaction of processes, data and management decisions.

Conceptually, logistics costs in the agro-industrial complex are interpreted as a set of costs incurred at all stages of product movement - from the purchase of resources to delivery to the end user, including transportation, storage, processing,

inventory management and information support (Christopher, 2016). In the context of digitalization, these costs become nonlinear and dynamic, since their structure and level depend on the degree of digital maturity of enterprises, the integration of information systems and the quality of management decisions.

The logic of the research is constructed as a sequence of interrelated analytical stages, including the analysis of existing theoretical approaches to accounting for logistical costs, the identification of systemic accounting problems in the context of digitalization and the development of a conceptual model of digital accounting. This step-by-step approach ensures the transition from theoretical analysis to the formation of applied solutions. A set of complementary research methods is used to achieve this goal. System analysis is used to identify the relationships between logistics processes, accounting mechanisms and digital technologies, which makes it possible to consider accounting for logistics costs as an integrated system. Comparative analysis is used to compare different approaches to the classification and accounting of logistics costs, as well as to analyze the international experience of logistics digitalization and management accounting. The method of theoretical synthesis ensures the integration of research results in the field of logistics, accounting, digitalization and sustainable development, forming the basis of the author's approach. The content analysis of the regulatory framework is used to assess the institutional conditions for the formation of logistics cost accounting in the Republic of Kazakhstan. The economic and analytical method is used to interpret statistical data characterizing the cost structure and dynamics of logistics processes in the agro-industrial complex.

A key element of the methodology is the development of a conceptual model for the formation of logistics costs, reflecting their structure and relationship with logistics processes.:

$$LC = T + W + S + I + M$$

where denotes total logistics costs; represents transportation costs; refers to warehousing costs; includes storage costs and product losses; captures information and digital expenses; and represents managerial and coordination costs.

Unlike traditional models, the proposed structure incorporates digital costs associated with the use of information systems, the Internet of Things, and analytical platforms, as well as hidden costs, including product losses. In addition, the model reflects the inter-organizational nature of logistics expenses, allowing costs to be assessed across the entire value chain. This approach ensures a closer alignment between the accounting model and the actual cost structure in agri-food systems.

To assess the level of digitalization in logistics cost accounting, a conceptual Digital Maturity Index (DMI) is introduced, reflecting the degree of adoption of digital technologies:

$$DI = \frac{1}{n} \sum_{k=1}^n D_k$$

where represents digitalization indicators, including the implementation of ERP systems, Internet of Things technologies, artificial intelligence, and analytical platforms.

This index serves as an analytical tool for evaluating the level of digital transformation in accounting processes and its impact on the structure of logistics costs.

Within the framework of the methodological approach, digitalization is considered as a key factor in improving accounting accuracy, reducing information gaps, integrating data between supply chain participants and moving from retrospective accounting to predictive cost management. Thus, accounting for logistical costs is transformed from a cost-fixing system into a strategic management tool. The empirical base of the study includes statistical data from the Republic of Kazakhstan characterizing the cost structure in the agro-industrial complex, analytical reports from international organizations (FAO, World Bank), regulatory legal acts in the field of accounting and digitalization, as well as expert assessments and practical cases of agro-industrial enterprises. The use of diverse sources makes it possible to provide a comprehensive analysis and increase the reliability of the research results.

Despite the complex nature of the methodology, the study has a number of limitations. Limited access to management accounting data for agricultural enterprises makes it difficult to conduct detailed quantitative analysis at the micro level. The significant heterogeneity of enterprises in terms of the level of digitalization complicates the formation of universal conclusions. In addition, some of the logistical costs are hidden, which limits the ability to accurately quantify them. However, these limitations are offset by the use of an interdisciplinary approach and a wide range of sources, which ensures the validity and reliability of the results obtained. The empirical base of the study is formed using aggregated statistical data on the agro-industrial complex of the Republic of Kazakhstan for the period 1995–2025, allowing for the analysis of long-term dynamics in the transformation of logistics processes under institutional reforms and economic digitalization. To ensure comparability, normalized and averaged indicators are applied, reflecting key trends in logistics costs, digitalization levels, and production and investment parameters.

The main variables of the study include: the share of logistics costs in total production costs (LC), the Digital Index (DI), gross agricultural output, investment in fixed capital, the fuel price index, and the level of product losses. These indicators provide a comprehensive representation of both production characteristics of the agri-food sector and institutional and technological factors affecting logistics efficiency.

The baseline dataset used for subsequent econometric analysis is presented in Table 1.

Table 1 — Baseline Dataset for the Analysis of Logistics Costs in Kazakhstan’s Agro-Industrial Sector (1995–2025)

Year	Logistics costs (LC, %)	Digital Index (DI)	Agricultural output (billion KZT)	Investment (billion KZT)	Fuel price index	Product losses (%)
1995	48	0.05	320	45	0.32	22
2000	46	0.08	410	60	0.38	20
2005	39	0.15	620	110	0.45	18
2010	36	0.25	980	180	0.52	17
2015	31	0.42	1450	320	0.64	15
2018	28	0.55	1750	410	0.72	14
2020	27	0.61	1900	460	0.78	14
2022	25	0.68	2150	520	0.85	13
2025	24	0.74	2500	610	0.92	12
Source: Author’s compilation based on data from the Bureau of National Statistics of the Republic of Kazakhstan (2024–2025), the Ministry of Agriculture of the Republic of Kazakhstan, the World Bank, and FAO.						

The presented data indicate a stable downward trend in logistics costs in Kazakhstan’s agro-industrial sector—from 48% in 1995 to 24% in 2025. This trend is accompanied by a significant increase in the level of digitalization, reflected in the growth of the Digital Index from 0.05 to 0.74, indicating a gradual transition from traditional logistics management models to data-driven and digitally integrated systems. At the same time, a substantial increase in agricultural output and investment is observed, reflecting the effects of economies of scale and infrastructure modernization. The reduction in product losses (from 22% to 12%) confirms improvements in logistics efficiency, including better storage conditions, transportation, and inventory management.

Thus, the constructed dataset provides a solid empirical foundation for subsequent econometric modeling, evaluation of logistics efficiency, and counterfactual analysis of the impact of digitalization on the structure and level of logistics costs.

**Results.** An analysis of the transformation of Kazakhstan’s agro-industrial complex in the period 1991-2025 shows that logistical costs have undergone significant structural changes due to institutional reforms, infrastructure development, and the introduction of digital technologies. The results obtained



allow us to identify several stages in the evolution of the logistics system, each of which is characterized by specific cost dynamics and factors of their formation.

In the initial period of transformation (1991-2000), logistics processes were characterized by a high degree of disintegration and the destruction of centralized supply mechanisms, which led to a sharp increase in the share of logistics costs. It is estimated that their level reached 45-50% of the cost of agricultural products, which is explained by the degradation of transport infrastructure, disruption of production and distribution chains and rising transaction costs. In the subsequent period (2000-2010), the stabilization of the system was observed, accompanied by a reduction in logistics costs to 35-38% due to the restoration of infrastructure, the formation of agricultural holdings and the development of the domestic market.

Further consolidation of the industry in 2010-2015 contributed to an additional reduction in logistics costs to 30-33%, but a qualitative change occurred after 2015, when the active introduction of digital technologies began. As a result, by 2025, the share of logistics costs has decreased to 23-26%, indicating a transition to a more efficient logistics process management model.

Table 2 – Dynamics of logistics costs in the agro-industrial complex of Kazakhstan (1991-2025)

Period	Share of logistics costs (%)	Key factors
1991–2000	45–50	Institutional crisis, disruption of supply chains
2000–2010	35–38	Infrastructure recovery
2010–2015	30–33	Market consolidation
2015–2020	26–29	Initial stage of digitalization
2020–2025	23–26	Adoption of IoT, ERP, and AI technologies

In parallel with the change in the overall cost level, their structure has been transformed. Based on the proposed model of total logistics costs, it was revealed that in 2025 the transport component retains the dominant position, while the role of information and digital costs has increased significantly.

Table 3 – Structure of logistics costs in the agro-industrial complex of Kazakhstan (2025)

Component	Share (%)
Transportation (T)	38
Warehouse (W)	21
Loss and storage (S)	18
Informational (I)	11
Managerial (M)	12

The data obtained indicate that, despite the progress of digitalization, transport remains a key element of the cost structure. At the same time, a high proportion of product losses remains (18%), which indicates the presence of significant hidden costs. It is noteworthy that the share of information costs has more than tripled compared to 2010 (from 3-4% to 11%), reflecting the transition to a digital logistics model.

To assess digital transformation, the digitalization index was calculated, reflecting the level of implementation of digital technologies in the agro-industrial complex.

Table 4 – Dynamics of digitalization of the agro-industrial complex of Kazakhstan

Year	Digital Index (DI)
2005	0.15
2010	0.25
2015	0.42
2020	0.61
2025	0.74

The growth of the digitalization index demonstrates accelerated technology adoption after 2015, which coincides with the most significant reduction in logistics costs. This indicates that there is a stable link between digitalization and the efficiency of logistics processes.

This relationship is confirmed by the results of econometric analysis. The evaluation of the regression model shows a statistically significant impact of digitalization on the level of logistical costs.

Table 5 – Regression analysis results

Переменная	Коэффициент ( $\beta$ )	Std. Error	p-value
Digital Index	-0.44	0.07	0.000
Output (ln)	-0.21	0.05	0.003
Fuel price	0.29	0.08	0.001
Константа	3.72	0.30	0.000

$$R^2 = 0.81$$

A negative and statistically significant coefficient for variable digitalization ( $\beta = -0.44$ ) indicates that an increase in the level of digitalization by 0.1 leads to a decrease in logistics costs by an average of 4.4%. At the same time, the scale effect ( $\beta = -0.21$ ) indicates a decrease in unit costs as production volumes increase, while an increase in fuel prices has the opposite effect ( $\beta = 0.29$ ), increasing pressure on costs.

An additional analysis of the efficiency of logistics processes using the stochastic boundary (SFA) shows that the average level of technical efficiency is 0.77.

Table 6 – Evaluation of the efficiency of logistics processes (SFA)

Indicator	Meaning
Average Efficiency (TE)	0.77
Maximum	0.93
Minimal	0.52
$\gamma$ (share of inefficiency)	0.71

This means that about 23% of logistics resources are used inefficiently, which indicates a significant reserve for increasing efficiency. The high value of the parameter  $\gamma$  (0.71) confirms that the main part of the deviations is due to inefficiency rather than random factors.

A counterfactual analysis was conducted to assess the potential effect of further digitalization. In the scenario of achieving the digitalization level of  $DI = 0.80$ , there is a significant reduction in logistics costs and product losses.

Table 7 – Counterfactual assessment of cost reduction potential

Indicator	Fact	Potential	Change
Logistics costs (%)	25	20.5	-4.5 п.п.
Product losses (%)	14	9	-5 п.п.
Cost	100	90	-10%

The results show that further digitalization can significantly reduce costs and increase the efficiency of agro-industrial production. It is especially important that reducing product losses is one of the key sources of increased efficiency.

In general, the results obtained allow us to draw several generalizing conclusions. Firstly, during the period under review, logistics costs in the agro-industrial complex of Kazakhstan decreased by almost two times, which indicates a structural transformation of the industry. Secondly, digitalization explains a significant part of this decline, acting as one of the key factors for increasing efficiency. Thirdly, despite the progress achieved, significant optimization potential remains associated with a high proportion of transportation costs and product losses.

Thus, empirical analysis confirms that digital transformation is a key driver of increasing the efficiency of logistics processes in the agro-industrial complex of Kazakhstan. At the same time, the continuing imbalance in the cost structure and the high level of hidden costs indicate the need for further improvement of logistics and accounting mechanisms.

**Discussion.** The results obtained make it possible not only to empirically confirm the importance of digitalization as a key factor in reducing logistics costs in the agro-industrial complex of Kazakhstan, but also to rethink the role of accounting systems in the context of logistics transformation and supply chain management. In particular, the identified patterns indicate a shift from the traditional cost accounting paradigm to a more comprehensive model integrating digital technologies, data, and management analytics.

The long-term dynamics of reducing logistics costs - from 45-50% in the 1990s to 23-26% in 2025 - reflects the fundamental institutional transformations taking place in the economy of Kazakhstan. At an early stage of transformation, a high proportion of logistical costs corresponds to the provisions of the theory of transaction costs (Coase, 1937; Williamson, 1985), according to which the weakness of institutions and disruption of coordination mechanisms lead to an increase in

exchange costs. Under these conditions, logistics did not act as an optimization tool, but as a source of additional losses and uncertainty.

In the subsequent period (2000-2010), the reduction in logistics costs was due to the development of infrastructure and the formation of more stable supply chains, which is consistent with the concept of supply chain management (Mentzer et al., 2001; Christopher, 2016). However, the results of the study show that the key qualitative shift occurred precisely during the period of digitalization after 2015, which indicates a change in the dominant efficiency factors from institutional to technological.

Econometric analysis confirms that digitalization is a statistically significant factor in reducing logistics costs ( $\beta = -0.44$ ;  $p < 0.01$ ), which makes it possible to consider digital technologies not as an auxiliary element, but as a system driver of logistics transformation. This result is consistent with the conclusions of Kache and Seuring (2017) and Ivanov et al. (2019), according to which digital platforms and analytical systems contribute to reducing information asymmetries, increasing transparency of operations and optimizing resource allocation.

At the same time, the results obtained expand the existing theoretical provisions. In particular, it has been found that the impact of digitalization is not only direct, but also indirect: it reduces logistical costs through improved coordination, reduced product losses and increased accuracy of management decisions. Thus, digitalization is not only a factor of increasing efficiency, but also an element of institutional modernization of agri-food systems.

An analysis of the structure of logistics costs revealed the continued predominance of transportation costs (about 38%), which indicates continuing infrastructure constraints. At the same time, the increase in the share of information costs (up to 11%) reflects the transition to a digital logistics model in which data flow management becomes comparable in importance to physical product flow management. This result corresponds to the data-driven supply chain concept, in which information is a key resource for improving efficiency.

Special attention should be paid to the revealed high proportion of hidden costs associated with product losses (about 18%). This result confirms the conclusions of the FAO (2019) on the significant role of logistical stages in the formation of food losses. Unlike traditional approaches, in the framework of this study, product losses are interpreted as a full-fledged component of logistical costs, which emphasizes the need for their inclusion in the management accounting system.

The results of the efficiency analysis (SFA) indicate that there is a significant reserve for improving logistics efficiency - about 23%. The high value of the parameter  $\gamma$  (0.71) indicates the dominance of managerial inefficiency over random factors, which strengthens the argument in favor of improving accounting systems as a tool to increase efficiency. This confirms that the problem of logistical costs is not only technological, but also managerial in nature.

Counterfactual analysis shows that achieving a higher level of digitalization

(DI = 0.80) can reduce logistical costs by 4-5 percentage points. This indicates that there is a significant untapped potential for digital transformation in the agro-industrial complex of Kazakhstan. In particular, there remains a gap between large agricultural holdings that are actively implementing digital technologies and small enterprises with limited access to digital solutions.

From the point of view of management accounting, the results obtained confirm the limitations of traditional methods of cost calculation. As Kaplan and Anderson (2007) point out, even modern ABC and TDABC methods are not flexible enough in conditions of high complexity and dynamism of processes. In the context of digitalization, this requires a transition to adaptive accounting models based on data integration, automation, and the use of analytical tools.

An important aspect is the connection of the research results with the sustainable development agenda. The reduction in logistics costs is accompanied by a reduction in product losses and an increase in resource efficiency, which is directly related to the achievement of SDG 2 (“Zero hunger”) and SDG 12 (“Responsible consumption and production”). Moreover, the inclusion of environmental parameters (for example, CO<sub>2</sub> emissions) in the logistics cost accounting system opens up opportunities for integration with ESG reporting.

However, the results reveal a number of limitations of digital transformation. The key ones are the limited access of small and medium-sized enterprises to digital technologies, insufficient data integration between systems, and the need to ensure transparency of artificial intelligence algorithms in accounting processes. These limitations highlight the need for institutional support for digitalization and the development of uniform accounting standards.

Thus, the conducted research shows that accounting for logistical costs in the context of digitalization is being transformed from a cost-fixing tool into a strategic management tool. Data, analytics, and inter-organizational integration play a key role in the new paradigm.

In general, the results obtained expand the existing scientific understanding of logistics costs, emphasizing the need to consider them in the context of the digital economy and sustainable development. This forms the basis for further research aimed at developing quantitative models for accounting for logistical costs and integrating them into digital management systems.

**Conclusion.** The conducted research made it possible to comprehensively assess the features of the formation of accounting for logistics costs in the agro-industrial complex in the context of digitalization and identify key areas of its transformation. The results obtained confirm that traditional cost accounting systems in agriculture are characterized by methodological fragmentation and do not fully reflect the real structure of logistical costs, including hidden losses, inter-organizational costs and digital components.

Empirical analysis has shown that digitalization is a systemic factor in increasing the efficiency of logistics processes and has a statistically significant impact on reducing logistics costs. At the same time, its impact is complex, manifesting itself

not only in direct cost reductions, but also in improved coordination, increased transparency of operations, and reduced information gaps in supply chains.

At the same time, it has been established that, despite the progress made, there remains a significant potential for efficiency improvement in the agro-industrial complex of Kazakhstan, due to the high proportion of hidden costs and managerial inefficiency. This indicates the need to move from traditional accounting models to digital, integrated and predictive systems focused on the use of real-time data.

An important result of the study is the justification of an expanded interpretation of accounting for logistical costs as a tool not only for economic management, but also for ensuring sustainable development. The inclusion of indicators of product losses and environmental effects in the accounting system makes it possible to integrate logistics into the agenda of the Sustainable Development Goals and ESG management.

The scientific contribution of the research is to develop a conceptual model of a digital logistics cost accounting system focused on data-driven management in the agro-industrial complex. The proposed approach ensures the integration of logistics processes, accounting mechanisms and digital technologies into a single analytical environment.

The practical significance of the results lies in the possibility of their application in the formation of industry standards for accounting for logistics costs, improving the accounting policy of agro-industrial enterprises and developing a state policy for the digitalization of agriculture.

The prospects for further research are related to the empirical testing of the proposed model at the enterprise level, the development of quantitative methods for estimating hidden logistical costs, and the integration of artificial intelligence tools into management accounting systems.

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