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CHEMICAL SCIENCES

AMINO ACID COMPOSITION OF THE STEM OF CISTANCHE TRIVALVIS, A PLANT FOUND AROUND THE KYZYLKUM DESERT

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Abstract

In this article, for the first time, using high-performance liquid chromatography, the amino acid composition and amino acid content in the underground part of the stem of the Cistanche trivalvis plant growing in the vicinity of the Kyzylkum desert of the Khorezm region of the Republic of Uzbekistan were studied, and the content of the following amino acids was determined: asparagine, serine, glutamine, histidine, lysine, alanine, alanine with valine, methionine, glutamate, tryptophan, phenylalanine, isoleucine, proline.

Keywords: Cistanche trivalvis, Kyzylkum desert of the Khorezm region, amino acids, Glutamine, Glycine, Asparagine.

Introduction Today, ensuring healthy nutrition of the population, eliminating the deficiency of various micro- and macroelements, vitamins and biologically active substances is one of the urgent problems in the world. As a result of modern lifestyle, environmental problems, malnutrition and stress factors, many metabolic disorders are observed in the human body. Therefore, the demand for biologically active food additives based on biologically active substances obtained from natural sources is increasing year by year. In recent years, the increased interest in plant-based biologically active additives compared to synthetic drugs is explained by their relative safety, good absorption by the body and fewer side effects with long-term use. In this regard, in-depth study of plants rich in medicinal and biologically active substances, determination of their chemical composition and assessment of the possibilities of practical application are of scientific and practical importance. Plants belonging to the Cistanche genus have long been used in Eastern medicine as medicinal plants with biologically active properties. The scientific literature notes that the representatives of this genus contain flavonoids, phenylethanoid glycosides, iridoids, polysaccharides, vitamins, and important macro- and microelements. These substances are important because they have antioxidant, adaptogenic, immunomodulatory, and metabolic support properties. However, the Cistanche trivalvis plant has been scientifically studied less than other Cistanche species, especially since systematic and comprehensive studies on its flavonoids, vitamins, proteins, amino acids, fats, carbohydrates, and macro- and microelements are insufficient. This does not allow us to fully assess the richness of this plant in biologically active substances and its potential practical significance. The issue of effective use of local plant raw materials found in Uzbekistan and the development of biologically active products that can replace imports is also relevant today. A thorough study of the chemical composition of Cistanche trivalvis allows us to evaluate this plant as a promising raw material for the development of biologically active food additives. In addition, the scientific results obtained will serve as a solid scientific basis for future research on the creation of biotechnological products based on this plant. Taking into account the above, this article, aimed at determining the chemical composition of Cistanche trivalvis, in particular the amount of amino acids, is relevant and scientifically and practically necessary.[1,2]

The aim of the study: To determine the amino acid composition and quantity of the stem part of Cistanche trivalvis, collected from the edges of the Kyzylkum desert in Khiva and Yangiarig districts of Uzbekistan (around Eshonrovot and Ulli Shurkul).

About the plant: Cistanche trivalvis is a chlorophyllless, obligate parasitic plant of the Orobanchaceae family, with pale yellow flowers on its stems, growing to a height of 20-50 cm (7.9-19.7 in). The stem is glabrous and yellow to purple-gray. The leaves are ovate-lanceolate, lanceolate, glabrous, and usually brown. The inflorescence is dense, more or less cylindrical. The corolla is broadly obconical, strongly curved, bright yellow, sometimes light purple, and naked. It is a parasitic plant distributed mainly in the Republic of Turkmenistan, Karakalpakstan, and Khorezm regions of Uzbekistan. Its main characteristic is that it absorbs its nutrients from the roots of host plants.[3]

Materials and Methods: The sample used was the underground stem of the Cistanche plant, collected in the Yangiarik district of the Khorezm region in May 2025. The plant sample was analyzed for qualitative and quantitative amino acid values using standard samples supplied by Sigma Aldrich (Germany). The determination was performed using a fluorescence detector (FLD) mounted on an Agilent 1260 II Infinity liquid

chromatography system manufactured by Agilent Technologies, USA. A Poroshell 120 EC-C18 column (150 mm × 4.6 mm × 4 µm), manufactured in the USA, served as the stationary phase. Pre-column derivatization was performed in an automated, programmable mode. For amino acid analysis, the mobile phases used were: Phase A—sodium dihydrogen phosphate solution (40 mM), pH 7.8, and Phase B—a mixture of acetonitrile, methanol, and water (in a ratio of 45:45:10), using a gradient mode.

Time | Phase A % (sodium dihydrogen phosphate solution, 40 mM, pH 7.8) | Phase B % (acetonitrile:methanol:water = 45:45:10).Table 1.

Table 1

Mobile phases for amino acid analysis

Time (min)	Phase A - sodium dihydrogen phosphate solution (40 mM), pH 7.8	Phase B - acetonitrile: methanol: water (45:45:10)
0.0	98	2
16	70	30
23	57	43
26	0	100
28	98	2
30	98	2

The flow rate was 1 ml/min, the thermostat temperature was 40°C, the injected sample volume was 5 µl, the analysis was carried out for 30 minutes, and the following chromatograms were obtained.

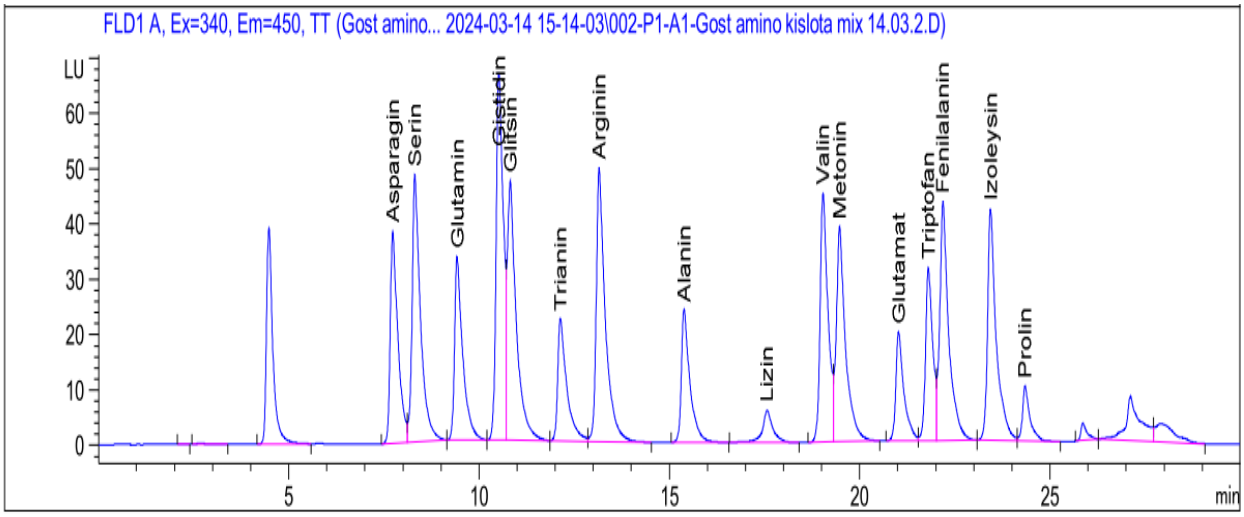

Figure 1*. Chromatogram obtained from standard samples of 16 different amino acids*

Hydrolysis of the amino acids contained in the sample was carried out as follows:First, all samples were ground to a size of 1 mm. A 5.0 g sample was ground and weighed to the nearest 0.001 mg using an analytical balance (FA220 4N). Next, the sample was placed in a 200 ml flask with a reflux condenser, 50 ml of hydrochloric acid (6 N) was added, and the flask was placed in a thermostat at 110°C. Hydrolysis was carried out for 24 hours with magnetic stirring. After hydrolysis was complete, the solution was cooled to room temperature, 10 ml was removed, and centrifuged for 10 minutes at 12,000 rpm. Then, 5 ml of the centrifugate was removed and neutralized with 6 N sodium hydroxide.

After this, 1 ml of the solution was filtered through a filter with a pore size of 0.45 µm, placed in a vial and the following results were obtained [4,5,6,7].

Results and Discussion: The results obtained are presented in Table 2.

Table 2.

Composition and quantity of amino acids in the underground parts of the stem of the plant Cistanche trivalvis, growing in the Khorezm region

№	Name of indicators	Underground stem parts Cistanche trivalvis (mg/g)	№	Name of indicators	Underground stem parts Cistanche trivalvis (mg/g)
1.	Asparagine	0.12	9.	Lysine	3.70
2.	Serin	1.57	10.	Valin	1.48
3.	Glutamine	0.55	11.	Methionine	0.62
4.	Histidine	0.44	12.	Glutamate	0.33
5.	Glycine	5.80	13.	Tryptophan	0.20
6.	Threonine	2.85	14.	Phenylalanine	0.17
7.	Arginine	1.76	15.	Isoleucine	1.15
8.	Alanin	0.77	16.	Proline	1.24

The obtained results were converted from mg/L to mg/g using the following formula:

$$M_{(A\min\ \ oacid)} = \frac{C * V}{m * 1000}$$

Where:

$M_{\text{amino acid}}$ —amino acid content (mg/g),

C —is the result obtained by HPLC (mg/l),

V —is the total volume of the solution used for hydrolysis (ml),

m— is the sample mass (g).

As a result of the conducted research, it was determined that 16 types of amino acids were present in the underground stem parts of the Cistanche trivalvis plant growing in the Khorezm region. Among the identified amino acids, the highest quantitative indicator was glycine, its amount was 5.80 mg/g. It was also noted that lysine — 3.70 mg/g, threonine — 2.85 mg/g, arginine — 1.76 mg/g, serine — 1.57 mg/g and valine — 1.48 mg/g.

The results of the analysis show that the underground stem parts of the Cistanche trivalvis plant are a natural raw material rich in biologically active amino acids. In particular, the high content of glycine indicates that this plant can have a positive effect on the functioning of the nervous system, participate in metabolism, and play an important role in antioxidant defense mechanisms.The relatively high content of lysine is also important. Lysine is one of the important amino acids involved in the processes of protein biosynthesis, immune system activity, and the formation of enzymes and hormones in the body. Threonine is involved in protein metabolism, liver function, and immunological processes. Arginine plays an important biological role in vascular function, nitric oxide metabolism, and regeneration processes.In addition, the presence of important non-essential amino acids such as valine, methionine, tryptophan, phenylalanine, and isoleucine in the plant allows us to evaluate the Cistanche trivalvis plant as a promising raw material for the production of biologically active food additives.The total amount of amino acids was calculated as follows: Total amino acid content = 22.95 mg/g.

This indicator indicates that the underground stem parts of Cistanche trivalvis contain a sufficient amount of amino acid complex. In particular, the relatively high content of biologically active amino acids such as glycine, lysine and threonine justifies the potential use of this plant in the pharmaceutical, food biotechnology and production of biologically active additives.

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CULTURAL SCIENCES

OVERVIEW OF INTERNATIONAL LEGAL RELATIONS THROUGH «TURANDOT»

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«ТҰРАНДОТ» АРҚЫЛЫ ХАЛЫҚАРАЛЫҚ ҚҰҚЫҚТЫҚ ҚАТЫНАСТАРҒА ШОЛУ

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Abstract

This article examines Turandot as a model of international and intercultural relations. The analysis is conducted from historical, theoretical, and cultural perspectives. Special attention is given to the contrast between Western and Eastern approaches to cultural representation. The study demonstrates that the opera reflects orientalist perceptions and symbolic inequality. Issues of cultural adaptation and stage interpretation are explored. Contemporary Chinese productions are analyzed as forms of cultural dialogue. The paper argues that artistic texts can function as instruments of cultural diplomacy. It concludes by emphasizing the importance of cultural representation in understanding international relations.

Түйіндеме

Бұл мақалада Тұрандот операсы халықаралық және мәдениетаралық қатынастардың үлгісі ретінде қарастырылады. Талдау тарихи, теориялық және мәдениеттанулық тұрғыдан жүргізіледі. Батыс пен Шығыс мәдениеттерін бейнелеудегі айырмашылықтарға ерекше назар аударылады. Шығармада шығыстандырушылық көзқарастар мен символикалық теңсіздік көрініс табатыны дәлелденеді. Мәдени бейімделу және сахналық интерпретациялау мәселелері қарастырылады. Қытайлық заманауи қойылымдар мәдени диалогтың үлгісі ретінде талданады. Көркем мәтіннің мәдени дипломатия құралы ретіндегі рөлі негізделеді. Халықаралық қатынастарды түсінуде мәдени репрезентацияның маңыздылығы қорытындыланады.

Keywords: Turandot, orientalism, cultural adaptation, representation, international relations.
Кілт сөздер: Тұрандот, ориентализм, мәдени бейімделу, репрезентация, халықаралық қатынастар.

«Тұрандот» операсы - музыкалық театрдың көрнекті туындысы ғана емес, сонымен қатар Батыс пен Шығыс арасындағы асимметриялық мәдени қарым-қатынастардың аясын айқындайтын таңбалар жүйесін құрайды. Қазіргі гуманитарлық ғылымда бұл шығарма классикалық махаббат хикаясы шеңберінен шығып, мәдени саясат, ұлттық бірегейлік және символдық үстемдік мәселелерімен тығыз байланысты зерттеу нысанына айналды.

Осыған байланысты тақырыптың өзектілігі «Тұрандоттың» халықаралық және мәдениетаралық қатынастарды түсіндірудің көркемдік үлгісі ретінде қарастырылуымен айқындалады. Осы мақаланың зерттеу нысаны Джакомо Пуччинидің «Тұрандот» операсы және оның әртүрлі тарихи-мәдени интерпретациялары. Зерттеу пәні шығармада көрініс табатын Қытай мен Тұран образдары, билік пен гендерлік қатынастар, мәдени бейімделу және олардың халықаралық-құқықтық

әрі мәдениетаралық қатынастар жүйесіндегі көрінісі.

Зерттеу пәнаралық сипатқа ие және әдебиеттану, мәдениеттану, өнертану, идеялар тарихы, сондай-ақ мәдениетаралық коммуникация теориясының тоғысында жүзеге асырылады. Мақала «Тұрандот» операсы Батыс пен Шығыс арасындағы халықаралық қатынастарды қалай бейнелейді және көркем мәтін мәдени және тарихи интерпретация үшін күрес алаңына қалай айналады деген зерттеу сұрағына бағытталып тұр. Бұл сұрақтың маңыздылығы жаһандану жағдайында мәдени өнімдердің тек эстетикалық құндылық қана емес, сонымен бірге мәдени дипломатияның, символдық биліктің және ұлттық өзін-өзі таныстырудың құралына айналуымен түсіндіріледі.

Зерттеудің теориялық-методологиялық негізін салыстырмалы талдау, рецептивті эстетика элементтері, мәдениеттанулық және өнертанулық тәсілдер, сондай-ақ ориентализм және мәдениетаралық коммуникация теориялары құрайды. Бұл әдістер «Тұрандотты» тұрақты мәтін ретінде емес, тарихи, саяси және мәдени контекстке байланысты өзгеріп отыратын динамикалық мәдени құрылым ретінде қарастыруға мүмкіндік береді.

Зерттеу жұмысының маңызды теориялық тіректерінің бірі Р.А. Алшановтың «Тұранбике туралы аңыздар» атты ғылыми-көпшілік очеркі. Аталған еңбек 2024 жылы Алматы қаласында «Тұран» университеті баспасынан жарық көрген және 112 беттен тұрады. Автор бұл еңбегінде Тұрандот сюжетінің шығу тегін шығыстық, әсіресе түркі-парсылық мәдени кеңістікпен байланыстыра отырып, Тұран ұғымының тарихи-мәдени мәнін ашады. Алшановтың концепциясы бойынша, Тұрандот бейнесі тек қытайлық контекспен шектелмей, кеңірек шығыстық өркениеттік кеңістіктің символы ретінде қарастырылуы тиіс. Жұмыстың практикалық маңызы - алынған нәтижелерді мәдениетаралық бейімделу, халықаралық қатынастар және мәдени дипломатия мәселелерін зерттеу мүмкіндігімен анықталады.

«Тұрандот» бейнесімен байланысты мәселе ұзақ уақыт бойы зерттеліп келеді. Шығарманың әдеби және сюжеттік бастамалары шығыстық баяндау дәстүрлеріне, ең алдымен парсы және түркі мәдени ортасында кеңге таралды. Пети де ла Круа өзінің француздық нұсқасын жаза отырып, шығыстық сюжеттерге сүйенді және Низами ықпалымен Тұран қызының атын «Тұранбике» (Тұрандот) деп атады [7]. Сонымен қатар, Р.А. Алшановтың очеркінде Низамидің «Жеті ару» поэмасында Тұран белгілі бір кеңістік ретінде көрініс табатыны, ал Тұрандот бейнесінің өзі Қытаймен емес, Тұран қызы деген түсінікпен байланысты екені айтылған [4]. Құбылыс табиғаты тұрғысынан «Тұрандот» - шығыстық ертегілік материал мен батыстық көркем өңдеудің қиылысында туындаған мәдени конструкт. Шығарманың қытайлық сахналық бейімделуіне арналған мақалада тікелей айтылған: операның сюжеті тарихи емес, ертегілік сипатқа ие, ал Гоццидің пьесасы XII ғасырдағы парсы дерегіне негізделгендіктен, қытай болмысын шынайы бейнелеуге претензия қоймайды. Демек, шығарманың генезисі біз халықаралық-құқықтық және мәдениетаралық қатынастар үшін маңызды мәселеге тап боламыз: елдің бейнесі ретінде нақты тарихи шындық емес, оның көркемдік жолмен құрастырылған үлгісі қызмет етуі мүмкін [3].

Бұл дискурстағы негізгі термин ол - ориентализм. Ориентализм «Шығысты ориентализациялау» процесі ретінде түсініледі, мұнда Батыс шығысты өз позициясынан құрастырып, оны батыстық сипаттау логикасына бағынған «өзгеге» айналдырады. Осы тұрғыдан алғанда, «Тұрандот» Қытайдың және жалпы Шығыстың батыстық қорқыныштар мен қиялдар арқылы қалай бейнеленетінінің мысалында айналады. «Тұрандот» төңірегіндегі ғылыми дискурс бірнеше негізгі бағыттар бойынша қалыптасады [2] . Біріншісі ориенталистік стереотиптерді сынаумен байланысты: Тұрандот «айдаһар әйел» бейнесінде, ал Лю - оған қарама-қайшы момын әрі құрбан болатын шығыс әйелінің стереотипі ретінде қарастыралады. Екінші бағыт ұлттық стереотиптерге қатысты: Қытай қатыгез және жабайы кеңістік ретінде көрсетілсе, Калаф тәртіп пен жеңіс әкелетін Батыстың символы іспеттес. Үшінші бағыт қазіргі заманғы зерттеулермен байланысты, мұнда назар аударма, сахналық бейімделу және туындыны Қытайдың өзінде мәдени оңалту мәселелеріне аударылады [1] . Жоғарыда айтылған, бір сюжет әртүрлі идеологиялық режимдерде қызмет ете алады. Еуропалық дәстүрде ол Шығыстың экзотикалық бейнесін бекітсе: XX ғасырдың соңы мен XXI ғасырдың басындағы қытайлық қойылымдарда ол мәдени бірегейлікті қайта пайымдау алаңында айналады. Осылайша, «Тұрандот» бір мезгілде әдеби, саяси және өркениеттік табиғаты бар құбылыс ретінде зерттеледі [6] .

Методологиялық тұрғыдан Тұрандотты зерттеу түпнұсқа туындыны, оның еуропалық интерпретацияларын және қытайлық сахналық бейімделулерін салыстыруға негізделген. Пэн Чэньнің зерттеуінде талдау үшін салыстырмалы тәсіл, рецептивті эстетика элементтері, мәдениеттанулық және өнертанулық талдау, сондай-ақ әртүрлі театр дәстүрлерінің белгілер жүйесін семиотикалық зерттеу қолданылатыны атап өтіледі. Бұл Тұрандотты тұрақты мәтін ретінде емес, саяси, ұлттық және эстетикалық аясына байланысты өзгеретін жылжымалы мәдени нысан ретінде қарауға мүмкіндік береді [8] . Шетелдік зерттеушілер негізінен ориенталистік сынға назар аударады. Хонг Юдің мақаласында еуропалықтардың Азияны қабылдауы Тұрандот жағдайында «Шығысты ориентализациялау» үлгісі екені дәлелденеді. Тұрандот пен Лю азиялық әйелдің қарама-қайшы батыстық стереотипі ретінде түсіндірілсе, Калаф бағындырушы батыстық ер адамның үстемдік фигурасы ретінде көрінеді. Мұндай тәсіл көркем мәтіннің тек мәдени ғана емес, символикалық-саяси теңсіздікті де қалай жаңғыртатынын көрсетеді. Мәселен, Бенанг Хуан мақаласында аударма және сахналық интерпретация мәселесіне ауысады. Зерттеуші Тұрандоттың жаңа қойылымдарында мәдени, нәсілдік және ген-

дерлік айырмашылықтарды «Батыс - Шығыс» деген қарапайым оппозицияда қарастыруға болмайтынын көрсетеді. Бұл стратегия халықаралық қатынастарды тек саяси субьектілер жүйесі емес, мәдени келіссөздер жүйесі ретінде түсіну үшін өте маңызды [3] .

Талдаудың негізгі нәтижелері бірнеше тұжырымнан тұрады. Біріншіден, «Тұрандот» Қытайдың бейтарап бейнесі емес. Екіншіден, оның сахналық тағдыры өнердің мәдени дипломатия мен ұлттық өзін-өзі интерпретациялау процестеріне қалай енетінін көрсетеді. Үшіншіден, туындының қытайлық нұсқалары батыстық мәтінді жай ғана түзету емес, еуропалық материал ұлттық дәстүр контекстінде қайта пайымдалған жаңа көркемдік құбылысты тудырады. Бүгінгі таңда өзектілік стратегиялары ең алдымен мәдениаралық бейімделумен байланысты, Пэн Чэнь зерттеуінде теориялық үлгілерді ассимиляция, интеграция, сепарация және маргинализацияны бөліп көрсететінін, бұл реттеинтеграция ең нәтижелі үлгі екенін атап өтеді [1] . Өйткені ол жаңа ортаға енген кезде мәдени бірегейлікті сақтауға мүмкіндік береді. Тұрандот үшін бұл идея өте маңызды: шығарма толығымен теріске шығарылмайды, ол қытайлық белгілерді, сюжеттік екпіндерді және ұлттық театр формаларын енгізу арқылы қайта пайымдалады. Қазақстан үшін бұл тақырыптың қолданбалы маңызы зор. Біріншіден, Тұранның мәдени-тарихи кеңістік ретіндегі бейнесі Орталық Азия дискурсымен және тарихи бірегейлік мәселелерімен тікелей байланысты (бұл әсіресе Р.А. Алшановтың очеркінде байқалады) [4] . Екіншіден, Тұрандотты зерттеу сыртқы мәдени мәтіндердің Еуразия халықтарының образдарын қалай өңдейтінін талдау үшін маңызды. Үшіншіден, Қазақстанның мәдени дипломатиясын дамыту жағдайында мұндай зерттеулер репрезентация, символикалық әділдік және меншікті тарихи-мәдени нарративтерді қорғау мәселелерін түсіну үшін қолданыла алады [7] .

Ғалымдардың сыни пікірлері және балама интерпретациялар Тұрандотқа қатысты сыни көзқарастар ең алдымен шығараманың Шығыс туралы батыстық қиял ретінде қарастырылуымен байланысты. Бір топ зерттеушілер мұнда Шығыстың қорқыныш, қатыгездік пен экзотиканың театрландырылған кеңістігі ретінде көрінетінін айтады. Тұрандот бейнесі - тарихи тұлға да, қытай ханшайымының мәдени шынайы бейнесі де емес, ол еуропалықтардың қорқуы мен әйел билігі туралы патриархалдық түсініктерінің қосындысы [2].

«Тұрандот» операсына қатысты ғылыми пікірталас бір ізді жүрмейді - зерттеушілердің бір тобы туындыны ориенталистік дискурстың айқын үлгісі ретінде сынаса, екінші тобы оны мәдени екіұштылықтың күрделі аймағы ретінде бағалайды. Осы екі бағыттың арасындағы кернеу мақаланың теориялық өзегін құрайды. Сыни-деконструктивті бағыттың өкілдері «Тұрандотты» ең алдымен Шығыс туралы батыстық қиялдың театрландырылған нұсқасы ретінде қарастырады. Бұл оқылым бойынша опера Шығысты қорқыныш, қатыгездік және экзотиканың шартты кеңістігіне айналдырады. Тұрандот бейнесі мұндай интерпретацияда тарихи тұлғаның да, Қытай мәдениетінің шынайы бейнесінің де орнын алмастырмайды: ол еуропалық санадағы «бөтеннен» қорқудың және патриархалдық үрейдің - яғни, билікке ие болған әйелден сезінетін аландаудың - символдық тоғысуын бейнелейді. Хонг Ю осы бағытта туындыны ориенталистік теория аясында талдап, Пуччинидің Қытайды Батыстың «өзгесі» ретінде конструкциялаудағы рөлін зерттеді [2] .

Алайда қазіргі зерттеушілердің едәуір бөлігі осы бір өлшемді оқылымнан алшақтайды. Бенанг Хуан «Тұрандотты» тек ориенталистік қате ретінде бағалаудың жеткіліксіздігін дәлелдей отырып, түрлі сахналық қойылымдардың стереотиптерді ашып қана қоймай, шығарманың мәдени, нәсілдік және гендерлік полифониясын - яғни, көпдауыстылығын - қалпына келтіруге ұмтылатынын көрсетеді. Бұл тұрғыдан алғанда, зерттеушінің назарын «Қытайды дұрыс бейнелеу» мәселесі ғана емес, театрдың мәдени қақтығыс жағдайында мағыналарды қалай тудыратыны деген іргелі сұрақ та тартады. Осылайша, «Тұрандот» зерттеулерінде екі методологиялық үрдісті бөліп көрсетуге болады. Біріншісі - деконструктивті үрдіс: ориентализм механизмдерін, колониалдық образдарды және символдық зорлық-зомбылықты әшкерелеуге бағытталған талдау [3] . Екіншісі - реконструктивті үрдіс: батыстық сюжеттің жаңа ұлттық контексте жаңа мағынаға ие болуын, яғни мәдени диалог тудыру мүмкіндігін зерттеу. Пэн Чэннің қытайлық театрлық бейімделулерге арналған зерттеуі дәл осы екінші үрдісті нақтылайды: Чжан Имоу сияқты режиссерлер Пуччини сюжетін жай ғана «түзетпейді» немесе «тазартпайды» - олар қытай сахнасының өз атынан сөйлеу құқығын қайтарып алатын толыққанды мәдени диалог орнатады.

Жоғарыда аталған зерттеушілерден өзгеше позицияны Р. Алшанов ұстанады. Ол Тұрандот бейнесін таза қытайлық контекстпен шектемей, оны кеңірек - Тұран кеңістігімен және образдың тереңдегі шығыстық тамырларымен - байланыстыратын өз концепциясын ұсынады. Бұл тәсіл туындының географиялық-символдық шекараларын кеңейтіп, «Тұрандотты» жалпы шығыстық мәдени жадымен байланыстыратын жаңа оқылым мүмкіндігін ашады.

Аңызға айналған Тұрандот бейнесі шынайы өмірде көрініс тауып,Ұлы Дала жерінде “Тұрандот” мүсіні тұрғызылды. Қоладан жасалған Нұрлан Әбішевтың бұл туындысы Тұран университетінің қаражаты есебінен, Алматы қаласында 2024 жылы 21 қазанда орнатылған. Бұл мүсіннің биіктігі - 180 см, диаметрі - 100 см, тұғырдың биіктігі - 50 см. Тұрандот бейнесі қазақ жеріндегі әйелдің еркіндігі мен даналықтың символы.[12]

Осы зерттеулердің жиынтығы маңызды методологиялық қорытынды жасауға мүмкіндік береді: «Тұрандот» операсының талдау нәтижелері зерттеуші таңдаған теориялық оптикаға - яғни, қандай сұрақтар қоятынына және қандай ұғымдық аппарат қолданатынына тікелей байланысты. Дәл осы себепті мақалада пәнаралық тәсіл ұстанылады: ориентализм сынын постколониалдық теориямен, мәдени аударма концепциясын рецептивті эстетика элементтерімен үйлестіре отырып, «Тұрандот» мәтінінің Батыс пен Шығыс арасындағы халықаралық мәдени қатынастарды бейнелеудегі рөлі жаңжақты зерттеледі [4] .

Жүргізілген талдау «Тұрандот» операсын халықаралық қатынастардың өзіндік көркемдік моделі ретінде қарастыруға негіз береді. Бұл жерде тікелей заңдық нормалар емес, халықаралық-құқықтық процестердің символдық эквиваленттері жұмыс істейді: билік пен шекаралар, мәдени репрезентация, өзін-өзі сипаттау құқығы және легитимділік үшін күрес. Осы тұрғыдан операның сюжеттік қозғаушы күштерін кемінде төрт аналитикалық деңгейде қарастыруға болады [7] .

Бірінші деңгей - символдық егемендік мәселесі . Туындының еуропалық нұсқасында Қытай іс жүзінде өз даусынан айырылып, сырттан сипатталған кеңістікке айналады. Бұл халықаралық қатынастардағы күшті актордың әлсіз актордың бейнесін оның тікелей қатысуынсыз қалыптастыратын жағдайының нақты аналогы болып табылады. Сөйтіп, көркем мәтін біржақты репрезентация механизмінің образдық баламасына айналады.

Екінші деңгей - мәдени юрисдикция мәселесі. Сюжет Шығыспен тығыз байланысты болғанымен, оның мағынасын ұзақ уақыт бойы батыс сахнасы анықтап келді. Тек XX ғасырдың соңында пайда болған қытайлық қойылымдар шығарманы өзге мәдени контекстке қайтара бастады және осылайша ұлттық бейнені өз бетінше интерпретациялау құқығын мәлімдеді. Халықаралық-құқықтық ұғымдар тілімен айтсақ, бұл процесті символдық реституция - яғни, жаһандық мәдени кеңістіктегі теңдік үшін күрестің бір көрінісі ретінде бағалауға болады.

Үшінші деңгей - зорлық-зомбылықтың легитимділігі туралы мәселе. Опера сюжеті ханшайымның шексіз билігі айқын көрінетін өлім сынағы төңірегінде құрылған. Алайда батыстық интерпретация дәстүрінде бұл зорлық-зомбылық «шығыстық жабайылық» ретінде таңбаланады, ал еуропалық зорлық-зомбылықтың тарихи формалары сахна сыртында, яғни талдау аясынан тыс қалады. Демек, бұл жай қатыгездік туралы сюжет емес - бұл халықаралық саясатпен тікелей параллельдері бар асимметриялық моральдық пайымдау тетігі: белгілі бір зорлық-зомбылық түрлері өркениетті деп жарияланса, басқалары жабайылық деп аталады. Осындай екі өлшемді моральдық баға берудің өзі де билік қатынасының айқын көрінісі болып табылады.

Төртінші деңгей - нарративтер күресі. Тұрандот операсы халықаралық қатынастардың тек дипломатия мен ресми келісімшарттардан ғана тұрмайтынын, сонымен бірге баяндаулар - яғни, дүниені суреттейтін мәтіндер мен бейнелер үшін де болатынын аңғартады. Қытайлық режиссерлер қойылымдарға ұлттық символдарды енгізгенде, жазалау сахналарын өзгерткенде және сюжетті жергілікті эстетикалық нормаларға бейімдегенде, олар жай ғана спектакль жасамайды. Олар дүниенің балама бейнесін ұсынады. Осылайша, көркем мәтін жұмсақ күш пен мәдени дипломатияның нақты инструментіне айналады.

Жалпылай айтқанда, «Тұрандот» операсы мәдени туындының халықаралық қатынастар контекстінде атқара алатын рөлінің айқын үлгісін береді. Бұл туынды бір мезгілде бірнеше функцияны жүзеге асырады: ол Шығысты батыстық қиял аясында конструкциялайды, мәдени егемендік пен репрезентация құқығы үшін күрестің алаңына айналады және жаһандық мәдени кеңістіктегі теңсіздіктің символдық бейнесін бейнелейді.Мұны келесі тізбе және кесте түрінде көрсетуге болады:

Тізбе 1: Тұрандот халықаралық қатынастар моделі ретінде

Тарихи шығыс сюжеті → еуропалық өңдеу → ориенталистік опера → стереотиптерді сынау → қытайлық бейімделу → мәдениетаралық диалог → Шығыс бейнесін символикалық оңалту.

Кесте 1

Талдаудың негізгі деңгейлері

№	Деңгей атауы	Мазмұны
1	Сюжеттік деңгей	билік, сынақ, жаза.
2	Мәдени деңгей	Батыс Шығысты конструкциялайды.
3	Саяси деңгей	Интерпретация құқығы үшін күрес.
4	Халықаралық-құқықтық деңгей	Мәдениеттердің символикалық теңдігі және репрезентация мәселесі.

ҚОРЫТЫНДЫ

Зерттеудің нәтижелері «Тұрандот» операсын махаббат пен сынақтардың классикалық сюжетінен гөрі, мәдени дауыстар арасындағы теңсіздіктер туралы терең әрі күрделі көркемдік мәлімдеме ретінде қарастырудың негізділігін көрсетті. Анализдеу барысында анықталған дәлелдер туындының бірнеше деңгейде: эстетикалық, саяси, мәдени және халықаралық-құқықтық мағыналарда мән беретінін айғақтайды.

Зерттеудің теориялық базасын құрайтын мәдени репрезентация теориясы тұрғысынан, «Тұрандот» сюжетінің логикасы кімнің басқа халықтар жайлы әңгімелеу мүмкіндігі бар екенін, бірақ нақты билік жүргізушілердің кім екендігін көрсететін принципке сүйенеді. Осы логика бойынша халықтың өз бейнесіне құқық талап етуі тек мәдени талаптан тыс, кеңірек мәдени субъектілік құқықтарының бөлшегі болып табылады. Сондықтан қазіргі қытайлық және еуразиялық интерпретациялар шығарманың ерекше маңызын арттырып отыр, өйткені олар бұрын тек сырттан берілген мәдениеттерге өз дауыстарын қайтарудың символдық актісіне айналуда. Зерттеу барысында Тұрандотты өркениетаралық байланыс моделінің күрделілігін танып-білу қажеттілігі көрсетілді. Бұл модельде халықаралық-құқықтық аспектілер заңдық нормалардан гөрі репрезентация, мәдени легитимділік және символдық теңдік мәселелері арқылы байқалады.

Батыстық нұсқасы Шығыстың біржақты бейнесін қалыптастырғанымен, XX ғасырдың соңынан бастап белсенді түрде пайда болған қытайлық адаптациялар мәдени қайта қарау мен тең құқықты диалогтың шынайы мүмкіндігін ашып көрсетуде. Осы контексте «Тұрандот» операсында мәдени гегемония, ориенталистік дискурс, ұлттық бірегейлік және тарихимәдени образдарды интерпретациялау құқығы үшін күрес мәселелері тоғысады. Соңында атап өту керек: заманауи ғылымның халықаралық қатынастарды түсінуі мәдени мәтіндер мен олардың интерпретация механизмдерін ескермей мүмкін емес. Тұрандот - бұл тек Шығыс тақырыбында жазылған опера емес; ол өнердің халықтар мен мемлекеттердің образдарын қалыптастырудағы рөліне және символдық кеңістіктің нағыз саяси арена бола алатындығына дәлел болады. Сондықтан мұндай туындылардың пәнаралық талдауы филология мен өнертанудан бөлек, халықаралық мәдени әділдік, мәдени дипломатия және өркениетаралық диалог мүмкіндіктерін тереңірек түсіну үшін маңызды ғылыми міндет болып қала береді.

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ECONOMIC SCIENCES

INNOVATIONS FOR DIVERSE TENURE SYSTEMS OF PASTURE LAND IN CENTRAL ASIA

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Abstract

Pastoral agriculture is a way of life for many communities in Central Asian vast steppes and mountains and over time it has evolved and supported environmental protection of rangeland landscapes and herders' livelihoods.

Central Asian region currently in adaptation phase in ongoing socio-economic, ecological and political challenges and flexibility. In economic aspects important how pasture land can contribute for wellbeing and livelihood of herder's and local communities, and in social aspects we conclude that community based co-management of pasture land promote equal participation of herders, poor ,women and local, central governments for integrated sustainable management of local ecosystems. Therefore for this to happen there are need to introduce diverse system of pasture land tenure arrangements, based on rich traditions local communities and best practices of pasture management in the region. In this context this paper compares the land tenure system for pasture land use in Mongolia, Kyrgyzstan, Kazakhstan and Tajikistan.

Keywords: Central Asia, Pasture land, tenure systems, best practices

Introduction

Nomadic herding is a way of li*f*e for Mongols, Kyrgyz and Kazakhs as well as for other nationals and communities in Central Asia (CA), which is based on common pasture use practice. Traditionally, in Asia two types of agriculture: i) with pastoral agriculture and ii) with none-pastoral or settled agriculture, and main representatives of the first group countries are: Mongolia, Kazakhstan and Kyrgyzstan (Ykhanbai H., 2000).

Natural resources-based sector's development is currently background of the economy in Mongolia, Kazakhstan, Kyrgyzstan , Tajikistan, Turkmenistan and Uzbekistan.

All these are landlocked countries in CA with a low density population, and a comparatively lower degree of industrial development and higher portion of rural population.

Nomadic and semi nomadic pastoralists[1] in Central Asia largely contributing to food security, job opportunities and rural poverty reduction.

In next sessions we will explain and draw lessons and comparisons from a scoping studies carried out by the members of Asia Rangelands Initiative, supported by International Land coalition for the networking, mobilizing and influencing on different tenure systems for improved pasture land management and livelihoods for nomadic and semi-nomadic pastoralists in CA.

Why rangelands

In Central Asia the rural population particularly relies on livestock production, so their livelihood and the social life closely connected with pasture land use. Agriculture's share in the GDP in Mongolia, Kazakhstan, Kyrgyzstan and Tajikistan ranges from approximately 15.0 to 27,2% and pasture land covers between 45 to 72% of the entire territory of Mongolia, Kazakhstan, and Kyrgyzstan, so share of pasture land to the total territory higher than average of Asia (which is 1/3 of total territory of Asia) by more than 2 times in Mongolia and Kazakhstan , and by 1,4 times in Kyrgyzstan (Table 1).

[1] According to IFAD (2016) the total number of nomadic and semi-nomadic pastoralists in dry rangeland ecosystems including herders and populations linked with pastoral agriculture estimated, around 150,0 million from which : 50 million are in sub-Saharan Africa, 31 million in the Middle East and North Africa, 25 million in Central Asia, 10 million in South Asia, and five million in South and Central America

Table 1.

Main indicators of Central Asia's Pastoral Agriculture and Rangelands

Indicators		Mongolia	Kazakhstan	Kyrgyzstan	Tajikistan
Population	mln. pers	3,5*	20,1*	6,04**	8,74**
Total land area	mln .ha	156.5	272,500	19,995	14,31
Pasture land	mln .ha	112,7*	182,00	9,068	3.8
Forest land	mln .ha	12,280*	22,9*	2,620	0,412*
Share of pasture land to total land area	%	72	66,8	45,4	26,6
Animal herd size	mln.head of animals	62.6*	31,3*	8,0	6,5
Number of herder's family	thous.HH	*201,000**	320,0**	1,700	
Number of herder's	thous.per	*317,8**	360,0***	13,0	
Share of Agriculture to GDP	%	*15,0**	7,0*	24%	27,2*
Share of Animal Husbandry to Agriculture GDP	%	*86,5**	3,0	42%	
Share of mining land to total land area	%	6,96*	na	0,025	

*2025, **2020, *** estimation

Source: Ykhanbai H., Tazbaeva S., Dorj T.

In all Central Asian countries, almost 59-88% of pasture and agriculture land is degradated by different levels. This severe land degradation in Central Asia reducing productivity of animal husbandry and threatening the livelihoods of millions of pastoralists. Land degradation has a serious socio-economic impact in these CA countries. A large proportion of the environment degradation and soil contamination covered about 59% of the area of Kazakhstan. According very recent estimation more than 76 % of pastureland in Mongolia is degradated and subject for future desertification. The cost of pastureland degradation in Mongolia, calculated by the net price of additional fodder required for the estimated number of livestock that exceeds the maximum herd capacity that is estimated to be 9.5 billion MNT annually (Ykhanbai H., 2011). Currently in Mongolia rangelands and grass species are being lost its traditional natural condition. Livestock number maximization results in declining land, animal productivity, herder's asset value and income and increased vulnerability to natural risks Compared to fresh pastures, on overgrazed pastures live weight of ewes is lower by 8 kg, milk yield by 2.5 folds and cashmere yield by 8%.

As most of the commons have been encroached with the problem on interactions of pasture land and arable farming systems, and in many cases the pastoralists and other marginalized people lost in these conflicts. This situation is same in CA, but its severity is higher in Kazakhstan and Tajikistan, than Mongolia and Kyrgyzstan. As arable land has less than 1% of territory of Mongolia comparatively these conflicts on land use rights between pasture and arable land is minimal in many parts of the country. Moreover, pastoralists of Central Asia has greatly impacted by land use changes due to exploration industries development. Nowadays expansion of mining business has as positive effect in terms of economic development, but has also as negative effect for the pasture land use rights of herder's in Central Asia, particularly in Mongolia, Kyrgyzstan and Kazakhstan, as these countries has a significant potential for the development of the mining industry, as they launch of new businesses after the transition from old soviet stile management system and creation of new job places. But for national government economic benefits of mining considered to be higher agenda, particularly in recent economic and financial instability in these countries. Mongolia has almost more that 6,9 % of land for the mining (Table 1) exploration and exploitation licenses. In Kazakhstan mining sector also heavily impact for the growing desertification and environmental degradation.

As shown our scoping studies, mining sector booming in all these CA countries, as all of them has high natural and mineral resources rich endowment. In regard to the pasture land and land use it has some negative impacts for herder's communities in Mongolia, due to the exploration and exploitation in the land, which was use as pasture and grazing of animals. In terms of forest management also some disagreements with forest communities and mining companies in Mongolia and Kyrgyzstan.

Pastoral communities

Animal husbandry is the main occupation of the pastoralist communities in CA that has long time traditions living in harmony with nature and belongs to people who are the most marginalized and highly dependent on the use of common resources, as rangelands.

In most cases, pastoral agriculture and pastoralists are outside of priority concerns of the government, which arises issues in current socio-economic development, rural livelihood and poverty elevation. It is also high than in other places due to the fact that the countries in CA are still in the process of transition and facing some institutional and agro-ecological changes such as population growth, climate change, globalization of markets, changes in demand for animal products, decentralization of governance, as well as changes in tenure systems. All these changes are disrupting the frameworks of traditional operations done by pastoral societies and the "burning" socio-economic and political developments to taking place in Central Asia. These changes have a large impact on the life of nomadic herders.

Currently, there are some changes in livestock distributions, such as, high growth of herd size in the region, particularly in Mongolia, which leads to exceeded

pasture capacity and overgrazing. There is an existence of economic barriers to seasonal pasture use in all countries of the region and abandoned large areas of pasture in Kazakhstan, and livestock concentration around settlements of Kazakhstan, Kyrgyzstan and Mongolia. The new livestock owners of the urban area highly influenced the pasture management in Mongolia and Kazakhstan, and currently in the region pastoral agriculture extends from being an individual herders of Mongolia and smallholders of Kyrgyzstan and Tajikistan to the large commercial livestock operations in Kazakhstan.

Pastoralists of the Central Asia have been working under the heavy pressure of current climate events, *dhzut* and natural disasters. Currently, poverty is also connected with the degradation of natural resources. In the *dhzut* winter of 2009-2010, 8.4 million head died, that is equal to 15 % of total herd size, increasing poverty in rural areas. By the latest estimation of NSO, where the World Bank methodology was used , poverty headcount index in Mongolia stands at 29.8 percent in 2011, poverty depth amounts to 7.6 percent which represents a drop of 3.7 percentage points, poverty severity is at 2.8 percent which is 1.8 percentage points less than in 2010 (NSO, 2012). The world's first index-based livestock insurance was launched in Mongolia in 2005, however take-up has been slow due to the lack of awareness and affordability.

In relation with equity, both women and men play important, but different, roles in the management of natural resources in nomadic pastoralism, where women's participation in the use of natural resources, decision-making, and implementation has been undervalued in all countries of CA, which is one of the sources of poverty.

In CA, herders' income source is mainly from animal husbandry. This situation urges individual herders', in an open market situation, to raise more and more animals in order to increase their income and welfare, in detriment of the natural resource base. This trend has become one of the major difficulties that CA'S pastoral agriculture is facing. It makes finding solutions or innovative tenure systems for pasture degradation and overgrazing a serious challenge.

Often pastoralists face a lack of tenure security due to poor attention or investment in developing tenure systems that work in these complex social and environmental systems. This means that pastoral lands are vulnerable to expropriation and encroachment, which when occurs leads to the loss and fragmentation of grazing areas, access to water and other important resources (Fiona F., 2017).

A shift in tenure systems

As commonly accepted, that tenure is how people *gain access to land and other natural resources*. Having secure and equitable access to natural resources can allow people to produce food for their consumption and to increase income. Inadequate and insecure tenure rights to natural resources often result in extreme poverty and hunger. The governance of tenure is a crucial element in determining if and how people, communities and others are able to acquire rights, and associated duties, to use and control land and natural resources. Many tenure problems arise because of weak governance, and attempts to address tenure problems are affected by the quality of governance. The eradication of hunger and poverty depend in large measure on how people, communities and others gain access to land and other natural resources. The livelihoods of many, particularly the rural poor, are based on secure and equitable access to and control over these resources. They are the source of food and shelter; the basis for social, cultural and religious practices; and a central factor in economic growth(VGGT, 2012).

The rangelands tenure system has its own specifics, such as: large areas of pasture land used by nomadic herder's and their communities without any clear borders; mobility of herding is strategic action to fit animals and overcome pasture degradation; seasonality of rangeland use; biodiversity conservation highest priority of rangelands; poor infrastructure and marginalized communities; livelihoods of herder's only dependent for grass growth in each year and seasons; herder's poor in terms of introducing economic incentives, as tenure systems; as well as none equal numbers of herd size by herder's households. Mobility refers to the practice of moving animals based on resource availability, mainly pastures and water. It allows pastoral communities to access fresh pasture and water by moving to resource-surplus areas. While this is supported under collective land tenure, it's constrained where land is under individual tenure. However, as the land tenure becomes individualized, strategies of commons can no longer be practiced. After the transition to a market economy they started to adopt innovative and different tenure systems of pastoral land management to adapt socio-ecological and political changes in the region.

There are special regulations and sub-laws on pasture land, where implementation of tenure arrangements in place for the given conditions and changes. In economic aspects important how pasture land can contribute for wellbeing and livelihood of rural population and communities. Therefore community based co-management of pasture land, as one of innovative tenure systems, with equal participation of herders, local and central governments pasture management, including recognizing traditional pasture use rights of herder's communities and integrated management of local ecosystems can greatly help for implementing SDG.

In the transition to a market economy countries of the region started to adopt innovative and different tenure systems of pastoral land. These tenure systems contributing to the independent economic development, decentralization, devolution of decision making and for the reduction of degradation of pasture land.

In Central Asian countries currently practicing different tenure systems**,** such as: state owned and common property, state managed systems, open access and mixed systems; individualized private ownership and lease/rented systems. CA region in social, economic and ecological terms stile in adaptation phase in ongoing socio-economic, ecological and political challenges and flexibility. Until early 1990's the five 'stan" republics of former USSR and Mongolia had a common mechanism of pasture management, which is dominated centrally planned state managed systems (Dorj

T., 2003). However after the transition to a market economy they started to adopt very different systems of pastoral property rights, like common property, open access in Mongolia, state managed systems in Kyrgyzstan, and Tajikistan; state owned individualized (private/rented) leasehold systems and private ownership in Kazakhstan (Table 2).

Pasture legislation is longstanding issue in Mongolia, as well as in other countries CA.Under these specifics in important role for legal, economic, ecological and social aspects of pasture land use in CA. In legal and policy innovations Central Asian region has broader experiences on legal side, such as "law on Pasture land"(2009) in Kyrgyzstan legalizing local pasture management committees in the country , "Law on Pasture" (2013) in Tajikistan clarifies roles and responsibilities of local and national organizations on pasture land use. Recent "Law on Pastures" (2017) in Kazakhstan legalize roles of local level pasture management friendship organizations and herder's associations, and "Land Law" (2003) and Law On Environment Protection (2006, 2012) in Mongolia has articles on the responsibilities and rights of local communities to use degraded pasture land. There are special regulations and sub-laws on pasture land, where implementation of tenure arrangements in place for the given conditions and changes.

Table 2

Pasture land tenure and management specifics in selected CA countries

Country	Legal support	Pasture land tenure	Grazing fee or pasture use payment	Mobility and use seasonal pastures	Community based pasture and natural resources management
Kazakhstan	Law on Pasture(2017)	Mixed tenure arrangements, such as private ownership, leasehold and common use	Some relationship between livestock ownership and registered pasture use with payment	large livestock operations increasingly common and relatively mobile	village-based grazing, but led to localized pasture degradation
Kyrgyzsatn	Pasture Law (2009)	Pasture state owned, no private ownership and leasing of pasture to herder's	Access rights to pasture by purchase of tickets, sold on an annual basis with pasture use payment	Seasonal pastures under the administration of local government	Management devolved to local Pasture Users Associations
Mongolia	Land law (2003) and Environment Protection Law (2006, 2012)	Open access for summer pasture , animals private, pasture land state owned	Herder's households exempts from pasture use fee	All seasons migration with Strong traditional systems of pasture use	Community based co-managements of pasture and Natural resources are introduced
Tajikistan	Pasture law (2013)	Pasture land state owned, but some pastures privatised	Pasture use payment system introduced	Settled pasture use and mobility only for distance pastures in summer	co-management approaches introduced with Pasture User Groups

Source: Scoping study by members of Asia Rangelands Initiative, 2017

However in recent years there has been a move to adopt different tenure systems of pastoral land management adapted to different socio-ecological and political contexts and processes of change in the region. All pastureland in Kyrgyzstan, Mongolia and Tajikistan belongs to the state. New laws and policies have been developed such as law on pastures in Kyrgyzstan and development of country-wide pasture user unions, and in Mongolia herder's communities organized as Co-management communities of natural resources (Amendment to Environment Protection Law). Alternatively in Tajikistan the majority of pasture has been allocated to private *dehkan* farms by "Law on Pasture" (2013). And in Kazakhstan a system of private ownership has been introduced (See Table 2).

There are change in livestock distributions, such as , high growth of herd size and exceeded *pasture capacity (Mongolia) e*conomic barriers to seasonal pasture use(all); large areas of pasture abandoned(Kazakhstan); Livestock concentrated around settlements(Kazakhstan and Kyrgyzstan); system fragmentation (in all). *The* new livestock owners: Herders (Mongolia, Kyrgyzstan); range from individual herders (Mongolia) and smallholders (Kyrgyzstan) to commercial livestock operations (Kazakhstan); herders and smallholders access remote pasture through collective herding systems (all) (Ykhanbai H., 2017).

In Kyrgyzstan the old management system was replaced by the new law "On Pastures" (2009). Rangelands degradation currently constitutes a great threat to

food security of the country and is changing from environmental to the category of perils threatening the sustainable development of Kyrgyzstan (Temirbekov A., Burkhanov A., 2016) . The main goals and objectives of the Law "On pastures" of the Kyrgyz Republic was to transfer of responsibility and control over the use of pastures in state ownership to local self-government bodies, prohibition of leasing and sublease of pastures, establishment and definition of pasture boundaries, the creation by local communities of pasture user associations, setting fees for the use of pastures for livestock, provision and use of pastures and pasture-based pasture resources, management and use of pastures in accordance with management plans and pasture use developed by the pasture committee and approved by the local government, provision of pastures to foreign users, use of pastures for other purposes (Egemberdiev A., Naizabekov B., 2017). But The Law of the Kyrgyz Republic "On Pastures" does not regulate pasture use in the territory of the State Forest Fund. According to the Forest Code of the Kyrgyz Republic, pasture use in the territory of State Forest Fund is regulated by a regulatory legal document developed by the republican state forestry management body, which currently requires the development of such a document (Burkhanov A., Tazhibaeva S., 2017).

Since then, pasture users have created 454 Pasture User Unions with pasture users as members, each with an executive body, the *Jaiyt* (Pasture) Committee. Seasonal pastures under the administration of local government and pasture Management devolved to local Pasture Users Associations. Access rights to pasture by purchase of tickets, sold on an annual basis to members and the leasehold system was introduced but later stopped with ban on leasing of pasture land in Kyrgyzstan.

In Tajikistan the majority of pasture has been allocated to private *dehkan* farms by “Law on Pasture” (2013). In particular, the law recognize a new set of institutions for pasture management, and regulations on pasture use fees. The Pasture User Unions are to be public independent activity bodies, established by pasture users for joint use of pastures (Sharifov A., Anoosh S., 2017). They may apply for and hold pasture lease rights from the state of Tajikistan. More co-management approaches in Mongolian and Tajikistan rather than state dominated management system in Kazakhstan. The basic problems of pastureland use in Kazakhstan are: i) degradation of pasture land due to distribution of traditional seasonal use practices ; ii) poverty and dissociation of the small-sized holders(owners) of livestock; and iii) absence of support of pastoral animal husbandry from the state.

New Law “On Pastures” in Kazakhstan(2017) regulates duties of national and local government structures and Local self-management bodies, communities and associations (Karibaeva K., Levin B., 2017). More than 10 years Kazakhstan practiced more mixed tenure arrangements, including private ownership for same pasture land, which is different from other countries of the region. Almost 1400 pastoral Small holders in the country now haven’t their own pasture land for grazing their animals.

The survey among 15000 herders shows that 67,3% of respondents supports the need for strong legal base , and 65,9% thinking better to allocate pasture to the herders communities (Ykhanbai H., 2011).

New Constitution of Mongolia (1992) provides that livestock are national wealth and shall be protected by the state. Currently pasture management regulated by Law of Mongolia “On Land “(2002) . Open access for most seasonal pastures and strong traditional systems of pasture use in Mongolia with comparison in other countries of the region (Ykhanbai H., Munkhbaatar D., 2017).

Ongoing legal and policy changes and transition stile need to address issue of co-management of pasture land, with more among the poor and wealthy herders, equity and transference and good governance. As herd size rapidly increased in all countries of Central Asia, overgrazing come as one of major reason of rangelands degradation. Currently herder’s in Mongolia, as well as in other countries of the region not much willing to cover environmental externality cost of overgrazing.

“The Law on Herders” (2024) has created new legal base to ensure the right of herders to use pastures in Mongolia. By this law securing the rights of pastoralists to use pastures has made a significant contribution to their sustainable livestock production and adaptation to climate change and combating desertification. The law also support recognizing importance of Rangelands and Pastoralists under the International Year of Rangelands and Pastoralists (IYRP),which will celebrated globally in 2026. Another new law in Mongolia on the “Legal status of the association of herder households” (2024) was a base of long years advocacy and consultation activities of our NGO and CSO groups to improve legal base of local herder’s institutions and tenure security for pasture land use in the country. The law provides key regulations for the use of pasture under contract in accordance with carrying capacity, activities in animal health, breeding, environmental protection, and organization of livestock product marketing at a single point for grading and selling (Ykhanbai H., et all , 2024).

Rangelands tenure system can be address this issue through introduction of grazing fee or other incentives and instruments for reducing pasture land degradation and for sustainable rangelands management. In this regard Mongolia and Kazakhstan can legalize innovative grazing fee system that can be collected by local herder’s associations in cooperation with local governments to spend grazing fee income for the improvement of pasture land use and for the conservation of rangelands biodiversity. As an option to diverse rangeland tenure system, we are currently lobbying Mongolian Government to impose the grazing fee on rangelands, due to high speed of growth the herd size in the country. Size of fee is estimated as a percentage from base value of land, on the base of sheep unit differentiated by livestock product yield, value, animal species, location and stocking rate. This can be realized as the Amendment to existing Land Use Payment Law (2005). This will improve economic incentive for the co-management of rangelands and reducing pasture degradation in Mongolia.

Devolution of management authority from national governments to local ones supporting by specific arrangements for co-management of pasture land and other natural resources ongoing in Mongolia, Kyrgyzstan and it's under the discussion and attempts in Kazakhstan, Tajikistan and Turkmenistan. Central Asia require to set the legal and economic base of tenure systems.

Rangelands tenure system can also supported by national policy documents and programs. In Mongolia was accepted several policy documents, such as National Program on Intensive Animal Husbandry (2003), State policy on Pastoralists (2009), and National Program on "Mongolian Animal"(2010) which guiding for the pastoral agriculture development in the country, particularly sound use of pasture land and improving livelihoods of herder's (Ykhanbai, 2017).

Existing scaling-up process of community based natural resources management approaches and allocation of pasture and other natural resources to the local communities also demanding public participation on decision making and its implementation. It's absolutely critical for all CA countries, where currently practicing on the decentralization of management and unlearning from soviet style top down administrative system. Public participation should be regarded according to the specifics of each country in CA in terms of their socio-economic development and the ecological condition, as well as it consider tradition, culture, institutional structure, and the capacity of different stakeholders.

The pastureland possession attempts in CA encouraging ownership mentality towards pastures in Kazakhstan, and different types of co-management arrangements in Mongolia, Kyrgyzstan and Tajikistan, encourages specifying pasture land boundaries of herder's groups and enforcing stocking density regulations, which helps in long run to the poverty reduction of herder's communities.

Currently the issue on recognizing traditional land use rights of herders and their communities has been considered in CA as suggested by VGGT. Disputes over pasture land use in CA involve competing claims to water and pasture use, land distribution the expansion of protected areas for the inclusion of customary grazing areas, the property rights in areas of mining exploration and extraction. Since 2016, our members of Asia RLI working with national government to recognize and to register traditional rights of herder's communities. As first case in CA the procedure on the registration of traditional pasture use right's was approved by National Agency of Land Management , Geodesy and Cartography of Mongolia, and this agency currently in cooperation with local governments and NGO's actively working on registration of these right's. So, it's also important now for other countries of CA. In regard that disputes between individual herder's and herders communities and the state are generally resolved by the national and local governors on the base of registered pasture use rights.

Securing secondary rights and access provides options to use extensive rangelands, forests, river swamp lands, etc. In combination, these resources form an important income source and element of risk reduction for the poor. Most of these lands have to be held in common property (due to high monitoring and enforcement costs in case of privatization or nationalization). Pasture monitoring activities conducted by local and national stakeholders in Mongolia and Kyrgyzstan can be good example for exchange experiences and collaborative learning in the CA region. We are agree that land tenure reform not only as a means of redistributing land but as an integral process for providing access, monitoring , recognition of traditional rights of pasture use, tenure rights and sustainable use of natural resources such as forests, water, seed, genetic resources and biodiversity (Michael K., 2017).

Land conflicts in Kyrgyzstan involve individuals, state actors, and entities across international borders. Many of these conflicts are related to land allocation, corruption and favoritism, and on a larger scale they also depend on the co-existence of different ethnic groups. Land disputes are generally resolved by formal and informal tribunals (Local village leaders and women's councils), which can apply customary laws that are not in contrast with formal laws. As discussed above in many cases mining companies entering without any Environmental Assessment Impact procedures, mitigation measures, and appropriate permission and licenses for that. According to the new procedure of the Government since end of 2017, all new mining licenses can be valid only after decision from Local Government. Previously mining companies not consulted with herder's communities and local governments, therefore it now can help on the implementation of Procedure on Public Participation to EIA processes, which our team was involved on it's development

Best practices

A scoping study on Rangelands Initiative in Central Asia, identifying best practices on pasture use tenure systems in Central Asia. These good practices range from those that focus on good governance and improved rangeland management systems, through to an increasing use of technology for both sharing of information relevant to pasture use or for registration purposes.

Of particular note is the co-management of pasture land in Mongolia, including use of mobile-based information sharing, and the recent development of an electronic system for better registering and managing pastoral committees in Kyrgyzstan and their access to rangeland resources.

i) Co-management of pasture land were first introduced in Mongolia since 2000.The increasing degradation of the natural resource base, widespread biodiversity loss and climate change impacts, require action at levels higher than the individual household or single community.

Amendment to the Mongolian Law on "Environmental Protection", firstly approved by Parliament on 18 November 2005, which legally gave start to the community based co-management of rangelands in Mongolia, by bottom-up approach. By this law the government legally recognized the creation and registration

of communities, as "*nukhurlul*", and established a legal framework for allocation of certain natural resources to the communities. The special Chapter on "Co-management of natural Resources" (2008, 2012) to Environment Protection Law was legalized and legally recognized Co-management approaches of natural resources with the roles of stakeholders, as communities and Community Associations.

According to this Law on "Environmental Protection", the new community guideline on: *"Procedure for the allocation of certain natural resources to the communities for their protection and sound use,"* was approved by Decree N114 of Ministry of Nature and Environment in 2006 and later on in 2009, 2012 was updated and improved for the need of full support and regulate pasture and natural resources in the country. Since then it has been the main policy and guiding document for the implementation of CBNRM approaches in the country at local and national level. The core element of the Procedure paves the way for herders to organize themselves (with or without external support) as a legally recognized 'community' in pursuit of the sustainable management of natural resources including grassland, water resources, wildlife, and other natural resources.

According to this Law the herder's communities for protection of nature referred as a voluntary organization for citizens that was established according to the Mongolian Citizen's Law 476, 481 in order to cooperate with citizens for the Protection of the environment as the basic of co-management agreement.

In Mongolia, as well as in other countries, study experiences shows that co-management of pastureland is special in comparison with forest, water and other resources management. Traditionally herders use pastureland according to certain kinship relationships combined with the sharing of a common area (*khot ail*, *sakhalt ail* or *neg nutgiinkan*) through sets of evolving community arrangements (Ykhanbai H. et al, 2011).

"The community" defined as such represents a community-based organization of local residents with similarities such as their language, life styles, natural resources base, linked together by strong kinship and friendship ties that have evolved over time, and they are rural people, which are most vulnerable to the poverty and climate change . They agree to operate as a social unit with common economic and ecological interests (see Figure1) as a means to improve pastoral livelihoods. Communities are mobile over time and in space: they follow their animals in the search of green pastures. As such, they represent a novel and Mongolian form of local organization. They differ from villages in other countries in terms of size (villages are usually larger units), purpose (villages seldom operate as socio-economic and ecological units), and relationship to the land (villages normally have a fixed location).

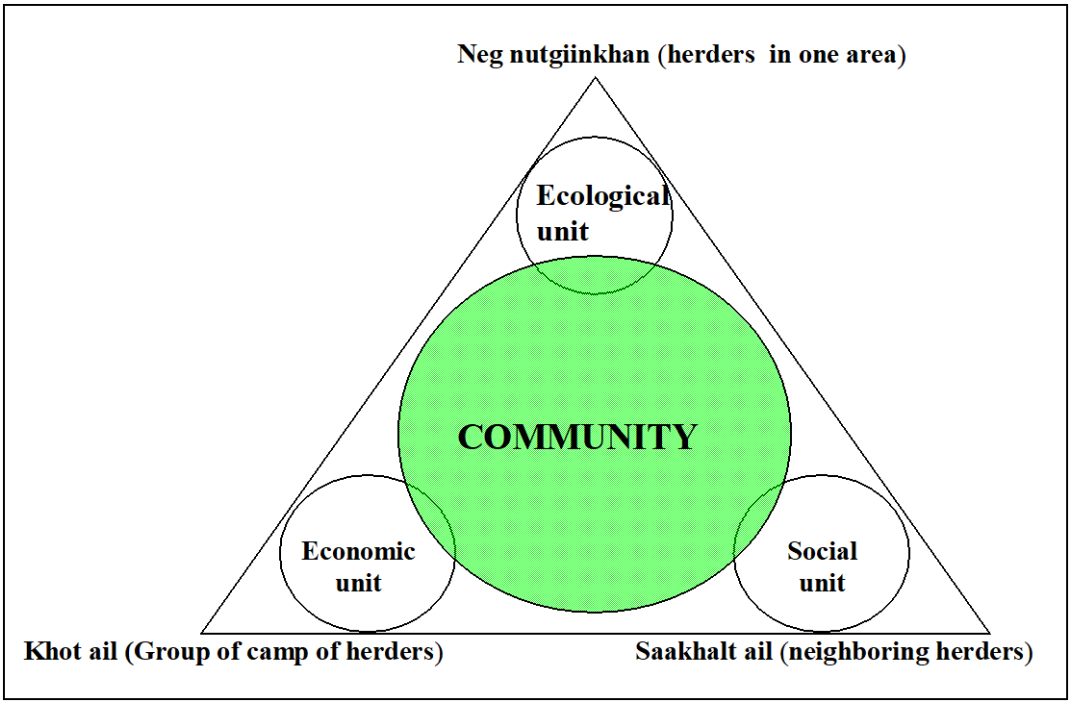

Figure 1: The logic of the new communities

Source:H.Ykhanbai, 2011

Some specifics of seasonal pasture land use was regulated according to articles 6.2.1, and 52.2. of the Land Law(2003) , "The Law on Herders" (2024), and "Legal status of the association of herder households" (2024) of Mongolia, which recognizes of importance of seasonal and *otor* pasture use during the hard climate events and protection of pasture land from over-grazing, based on land use traditions, pasture capacity and regional specifics.

At the end of 2025, at national level were registered about 1950 communities, associations or community-based groups (*nukhurlul*s) with a focus on co-management, encompassing about 17,500 households. They have leased from the state about 3400,000 ha area, including pasture, forest, hunting areas and land covered with rare plants (MNET report 2015). Also currently 1362 Pasture User Groups in Mongolia, involving about 63,5 thou-

sand herder's families, was established for the co-management of pasture land and improving their livelihood opportunities (Ykhanbai H., 2025).

These experiences show that co-management of grassland is special in comparison with forest, water and other resources management as herders use pasture by joint contracted arrangements local governments and other stakeholders with participatory monitoring of activities on pasture and rotation and shifting in local and community level. The results of community based co-management approaches was gradually improve livelihood and reduce pasture degradation. Co-management arrangements depending the local ecosystems was strongly supported by 60-90% of community members, and by 50-98% of local governors (Ykhanbai H., 2011).

However, herders wants over and over again that without concrete improvements in their livelihood, poverty reduction, it is hard to sustain co-management over time. This points to the fact that livelihood improvement requires ongoing research, targeted training, and policy and legal support. Communities are interested in economic capacity building in such areas as processing agricultural raw materials and dairy products and marketing; adapting and expanding agricultural mini-projects at the community level with a focus on full participation of community members; breeding better quality livestock or obtaining high-quality species and new breeds; benefiting from eco-tourism and improving rural services; using and marketing rare medical herbs; using forest resources; and participating in planting trees and perennial herbs.

In the CM and the participation one of important issue is gender , poverty reduction and equity. In study sites, as well as in communities we have some progress of equal participation of man and women on CM.

There are many supporting activities of co-management of pasture land and natural resources, however they should focus on improving livelihoods of local communities. One of such activities is using Information Communication Techniques (ICT) for disseminating information to the nomadic herder's in Mongolia.

Using ICT for reading weather by herders was important one. It is now theoretically as well as practically, important to study traditional nomadic or nomadic pasture use methods in this period , where climate change and desertification impact increases from year to year . Mongolian herders are moving from season to season, always dependent on the weather. Their livelihoods depend on the sound management of livestock and the natural resources that sustain their animals. However, herders continue to be challenged by weather vagaries and calamities. In particular, extremely cold winters known as *dzud*, cause major havoc.

Regarding to the using ICT for livelihood improvement the pilot test on "Reading the weather: using ICTs for climate risk management and herders' livelihoods improvement in Mongolia" supported by Regional Integrated Multi-Hazard Early Warning System for Africa and Asia, RIMES, was very important initiative, which was implemented by a team of researchers, communities, herders and other stakeholders led by "JASIL", in cooperation with National Agency of Hydrometeorology.

Early warning information in the form of weather forecasts that are community specific can assist herders to make better informed and less risk prone decisions concerning their every day livelihoods. The pilot experience suggests that an effective localized weather forecast system based on ICTs facilitates and strengthens interaction and cooperation among herders. This leads to the hypothesis that the scaling out of co-management could be made easier through the adoption of effective localized weather forecast systems based on ICTs (Ronnie V., Ykhanbai H., Tsogt J., 2012).

Implementation of new laws and legal bases for to realize the "2030 Agenda for Sustainable Development" and the SDGs its targets - specifically the launch of the "New Cooperative - Wealthy Herder" program in Mongolia , aiming to stabilize livestock income through collective action that enables herders to secure better pricing and reduce income volatility. As part of the initiative, the government has facilitated investment loans for cooperative member herders. These loans, provided by commercial banks, are supported by government incentives covering interest rate differentials and collateral guarantees ranging from 80-100% through the Credit Guarantee Fund of Mongolia, as another way of Ramsey's growth (Dorj.T., 2024). Within this framework, herders will have access to investment loans of up to 50 million MNT over a period of 60 months, with a nominal interest rate of 6%. This pivotal measure aims to lay the groundwork for herders to initiate cooperative endeavors and ultimately transition into agricultural producers, helps to implement for sustainable agriculture (SDG 2), poverty alleviation (SDG 1), pastoralist access to basic services and justice (SDGs 3, 4 and 16), economic growth (SDGs 5, 8, 9 and 10), as well for sustainable consumption and production of livestock products (SDG 12), By Law on Herders and the legal base for Mitigating the Negative Effects of Climate Change on Traditional Livestock Husbandry enhancing the resilience of Mongolia's pastoralists to the harsh effects of climate change. The law seeks to provide a legal framework for herders to adopt sustainable livestock practices that can better withstand severe winters and droughts, which have become increasingly common in Mongolia. is securing the rights of pastoralists to use pastures has made a significant contribution to their sustainable livestock production and adaptation to climate change and combating desertification(SDG 13), and promoting sustainable use of terrestrial ecosystems (SDG 15).

The results of our study on economics of environment and the development in Mongolia was included in the Vision 2050 (2020) , which is a government program aiming to improve social development, economic growth, and quality of life in the country. The overall vision for 2050 is for Mongolia to become a leading Asian country when it comes to its social development, economic growth and citizens' quality of life. The vision for 2050 includes the objective to contribute to international efforts to mitigate climate change by developing a low emission, productive and inclusive green economy following three stages: Stage 1 (2021-2030)

as a period to develop and establish a national green financing system and promote the use of environmentally friendly and clean technologies; Stage 2 (2031-2040) period in which smart consumption and production production should be developed, and increasing the internal and external sources of climate green financing; Stage 3 (2041-2050) continuously strengthen adaptation to climate change and improving the sustainable production and consumption (Dorj T., 2025)

ii) The Information System "Electronic pasture committee" in Kyrgyzstan **is** a program that allows to manage pastures and contains an electronic map of the territory and to keep a record of pasture areas of 454 Pasture User Unions (PUUs) in the country, which was created according to the "law on Pastures" in Kyrgyzstan (2009). It also records the number of pasture users and livestock, accounting for vaccination, payment for livestock and issued pasture tickets. The system includes a plan for pasture use, which includes terms, routes, pasture areas with yield and capacity data, which are updated annually by the committee. It's an innovative approach in pasture management, based on the local pasture user's associations (Egemberdiev A., Maratova E., 2017).

Results and conclusions of above innovative tenure systems of pasture management at local level are:

Co-management processes establish effective roles and responsibilities of the stakeholders who manage, directly or indirectly, livestock (privately owned), land and water and biodiversity resources (state owned) supports recognizing traditional rights of herder's . In terms of policy and legislative results, one of the biggest achievements has been the establishment of the legal foundation of herder communities as formally responsible for the allocation and management of natural resources at the local level. By changing and linking community rules with the new legal procedures governing nature and environment, a foundation for successful community-based interventions was built. Communities are involved in economic capacity building in such areas as processing agricultural raw materials and dairy products and marketing; adapting and expanding agricultural mini-projects at the community level with a focus on full participation of community members; implementing ecosystem monitoring and evaluation by creating pasture monitoring points and observations units, including weather forecast data dissemination, use and observation; breeding better quality livestock or obtaining high-quality species and new breeds; benefiting from eco-tourism and improving rural services; using and marketing rare medical herbs and protecting biodiversity; using forest resources; and participating in planting trees and perennial herbs. Scoping study of tenure systems show that co-management is an effective way of maintaining the natural resource base in pastoral communities while contributing to the improvement of the livelihoods of herders and reduction of poverty. Co-management requires vision and commitment, practical tools, incentives, and an enabling environment. Involvement in co-management is highly dependent on the interests of herders (and others with a stake in the natural resource base), but can be made to work and produce good results, ecologically, economically and socially. Co-management can be made to work if all stakeholders engage seriously, over a long period of time, learning by doing as they go along. Co-management encourages adaptability – a vital tool the face of the climate-induced challenges where Mongolia, and all other Central Asian countries face today.

Introduction of Electronic pasture committee allowed to start rationally and steadily to manage pastures, taking into account ecologically safe load on pastures, and showed its effectiveness, this mechanism allows you to quickly manage pastures and monitor the condition of pastures, monitor the processes of land degradation. It includes functions for counting livestock numbers, controlling vaccination, and also allows for the search for pasture tickets, the route for the transfer of livestock, the number of grazed livestock, the grazing area, the calculation of the amount of payment, accounting for payments, reporting.

Electronic pasture committee will promote the formation of an equitable and socially acceptable pasture distribution system, resolve conflicts of interest, ensure effective public control (reporting, transparency), and thereby improve the pasture management system at the local level. Our analyze shows that all leaders and members of the pilot pasture committees in Kyrgyzstan noted the importance of the electronic module, as the automated Information System made it very easy for them to work with pasture users. This gives confidence that the results obtained during its implementation will be sustainable and will continue in further work to improve pasture management practices in pilot pasture committees, and will undoubtedly have a positive impact on the state of the environment. The experiences of Electronic pasture committee of Kyrgyzstan and Community based Co-management arrangements of pasture land Mongolian currently recommended by Asia Rangelands Initiative to introduce in all other countries of Central Asia in line with specifics of their pasture management tenure system.

However, in the case of transitional economies in Central Asia, the full development and implementation of co-management approaches and electronic pasture committees requires adequate time as well as clear stipulation of what the government will and will not do to support agreements in terms of policies and legal tenure settings.

Conclusions and recommendations

The conclusions of this paper highlight that despite similar beginnings in the CA countries have taken different steps in pasture land tenure systems.

We conclude that community based co-management of pasture land, with broader participation of herders, local and central governments experienced more in Mongolia and Kyrgyzstan; however recognizing traditional pasture use rights of herder's communities advanced in Mongolia; and integrated management of local ecosystems wide use in Tajikistan and Mongolia; and national and local level data base for pasture management advanced in Kyrgyzstan; participatory monitoring of pasture land capacity in Mongolia; biodiversity conservation with national and local government lead in Kazakhstan and strong legal support for

pasture land tenure system in Kyrgyzstan, Tajikistan and Kazakhstan, as well as sectoral policy support on pastoral agriculture in Mongolia . These are some experiences of CA countries on pasture tenure system that can be exchanged with others in the region.

Tenure systems requires vision and commitment, practical tools, incentives, and an enabling environment. Innovative tenure systems can be made to work and produce well results, ecologically, economically and socially, but it need over period of time, learning by doing and good political support from the national governments.

Our collaborative initiative in the region shows that, if all stakeholders strongly support for the innovative tenure systems, including the co-management, allocation of pasture land and natural resources to local communities, innovative methods of pasture management, and improve data base for pasture use, then it can be a tool to overcome the pasture degradation and reduce poverty. For this to happen, the roles and responsibilities of all stakeholders need to be clearly established, and legal support should be put in place.

IThe participatiry assessment shows that during the testing period the annual income of herders households increased all study sites in 23-56%, and animal losses was eliminated, and pasture management was improved. Such kind of pilot tests also can be useful for local communities of herder's in other CA countries.

In countries of CA there are need to effectively guide the intended scaling-up process of community based co-management of pasture land and natural resources and it will be important to evaluate progress made to date in terms of implementation process, outcomes, as well as capacity development requirements. The Asia Rangelands Initiative and other multi-stakeholder platforms could be impact tenure system for livelihood improvement of herder's based on lessons learned in practice. Electronic pasture committee will promote the formation of an equitable and socially acceptable pasture distribution system, resolve conflicts of interest, but should be ensure effective public control and continuously government support.

Improved tenure systems of rangelands is a way to deal with pasture degradation and livelihood improvement of herder's in Central Asia. However in the case of transitional economies of CA, the securing tenure rights and can be effective by clear political and legal support by the government, and equal participation of all stakeholders, particularly herder's and local communities.

Notes:

Dehkan	*Farmers with animals in Tajikistan*
Neg nutgiinkhan	*community of herders living in the same place , Mongolian*
Khot ail	*Group or camp of herders, Mongolian*
Otor	*animal-fattening pasture , Mongolian , Kazakh and Kyrgyz*
dzhud	*hard winter, in Mongolian and Kazakh*

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CHALLENGES IN THE IMPLEMENTATION OF DIGITALIZATION IN AZERBAIJAN'S INDUSTRIAL SECTORS

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Abstract

The economic development of any state, amid rapidly evolving technological paradigms and the transition from Industry 4.0 to Industry 5.0 and beyond, is primarily determined by the pace of technological modernization of industrial sectors driven by digitalization. Digital technologies significantly reduce production costs by automating and robotizing manufacturing processes, optimizing value chains, and enhancing labor productivity, including managerial efficiency.

Despite governmental efforts, the economy of Azerbaijan, in addition to structural imbalances and low labor productivity, exhibits a relatively low level of overall technological development and slow transformation dynamics.

The aim of this paper is to analyze and systematize the outcomes of industrial digital transformation in leading regions—Southeast Asia, the Americas, and Europe—and to assess the state of industrial digitalization and robotics in Azerbaijan in comparison with these regions, as well as to identify the existing potential for accelerating industrial automation and robotization.

Keywords: industry, digital transformation, model, global development, and State Policy

I. Introduction

In the contemporary stage of civilizational development, the primary objective of scientific and technological transformation is to ensure a sustained increase in economic efficiency and to promote stable economic growth.

In the 21st century, key trends shaping the pace and direction of industrial development have become fully evident, including: the acceleration of technological progress and the emergence of new industries on this basis; the expanding use of alternative and renewable energy sources; and the global advancement of communication technologies and supply chain logistics, which has led to the large-scale relocation of industrial production to Southeast Asia.

The intensification of these processes has generated two major effects. On the one hand, production costs have declined, consumer prices have decreased overall, and production volumes have expanded. On the other hand, processes of deindustrialization have emerged and intensified in previously industrialized countries, many of which have transitioned toward service-oriented economies.

These transformations have been driven by economic development and the need to meet growing societal demands, which increasingly conflict with the limitations of the resource base, as well as by the evolving technological capacity of industry as a key sector determining the structure, level, and pace of both national and global socio-economic development. In this context, fundamental science, applied competencies, and innovation play a decisive role in shaping the direction and speed of industrial technological transformation.

By 2025, fourteen years have elapsed since Germany announced its transition to industrial development based on the Industry 4.0 concept (the Internet of Things (IoT), cloud computing, big data, and smart manufacturing). Over this period, the rapid expansion of digital technologies and their deep penetration into the production sphere—according to various estimates, the global market for such technologies is projected to exceed USD 165 billion by 2026—has initiated not merely an evolutionary shift but a transition toward Industry 5.0.

This new paradigm предполагает, through the integration and convergence of artificial intelligence (AI) and robotics, not only the establishment and further development of effective human–machine interaction but also the potential elimination of human involvement as a risk factor in most, if not all, production processes. Among the technological components of Industry 5.0, AI technologies are particularly prominent, enabling the automated reconfiguration and self-optimization of robotic production systems, advanced big data analytics (including cost data), and demand forecasting [1-4].

In the European Union, despite an early start (Germany's Industry 4.0 initiative) and the launch of the "Digital Decade: Europe's Digital Targets for 2030" program [European Commission, 2026], which defines the trajectory of digital transformation, interim assessments based on the Digital Economy and Society Index (DESI) [European Commission, 2026] indicate that

current progress is insufficient to achieve the stated targets, even though nearly one-fifth of the EU budget is allocated to industrial digital transformation measures.

In its conclusions, the European Commission outlines both an assessment of the challenges and its policy vision for addressing them. It calls on EU Member States, in addition to closing the existing investment gap and accelerating digital transformation, to harmonize digital principles necessary for launching cross-border projects and to develop a legislative framework for a new governance initiative—the "Digital Compass"—aimed at steering the pace of digitalization.

Furthermore, it is important to note that within the European Union, industrial modernization is pursued with due regard to regional specificities, as reflected in Smart Specialisation Strategies (RIS3). In this context, the development and diffusion of digital technologies are closely aligned with, and constitute a key driver for achieving, the United Nations Sustainable Development Goals (SDGs).The analysis of the conditions underpinning the digitalization of economic processes in the global economic space leads to the conclusion that one of the key trends of recent decades is *high-tech integration* (e.g., in Japan, Finland, and Sweden).

Development trajectories of post-industrial economies indicate the dynamic emergence of a "digital society" as an evolution of the "information society" under conditions of digital transformation. In this paradigm, advanced technologies permeate all spheres of human activity, shaping economic outcomes and contributing to a relative increase in societal welfare.

High-technology companies are both the primary creators and, in most cases, the dominant owners of the outputs of scientific and technological activity, thereby forming the core of knowledge-intensive business.

The growing importance of international technology exchange in the near term is driven by the accelerating digitalization of national economies. On the one hand, developed countries seek to expand the scale of research and development (R&D), enhance labor productivity, and strengthen the competitiveness of their products. On the other hand, newly industrialized countries, economies in transition, and developing nations face an acute need to broaden the adoption and diffusion of advanced technologies [5-9].

Japan. In addressing socio-economic challenges associated with population ageing and the shrinking workforce, the government prioritizes measures to stimulate the development, advancement, and deployment of cutting-edge innovative technologies aimed at building a "digital society." This policy orientation is formally articulated in official strategic documents, most notably the "Society 5.0" strategy.

The consistent and large-scale adoption of digital technologies—including cloud computing and artificial intelligence (AI)—has led to a substantial increase in organizational efficiency through the reengineering of technological and service-related business processes, particularly in the expansion of remotely delivered services.

Within this framework, the "Society 5.0" strategy envisions a profound transformation of Japanese society into a highly advanced "super-smart" society. It предполагает the pervasive use of robotics to address a wide range of social challenges—from service sectors (healthcare, commerce, retail, etc.) and routine household tasks to complex governance and decision-making processes enabled by AI. This spectrum encompasses solutions ranging from vending systems and assistive robots to advanced AI-powered humanoid robots.

China. China's experience in digital transformation and the deployment of robotics in industry warrants particular attention. In the People's Republic of China, the development of the digital economy, digital transformation, and the promotion of technological innovation have become key instruments for achieving high-quality economic growth and addressing socio-economic challenges.

This has been supported by a consistent and targeted state policy, which can be divided into three main stages [Zhang, 2024]:

- Stage 1 (2013–2015): government efforts focused on the development of ICT and the establishment of information infrastructure;
- Stage 2 (2016–2017): policy emphasis shifted toward the adoption of ICT and the digitalization of traditional industries;
- Stage 3 (2018–present**):** industrial policy has been oriented toward sectoral planning of the digital economy and the promotion of international cooperation.

A prominent illustration of China's industrial digital transformation is the emergence of "dark factories," where human labor is entirely absent. Production processes are fully automated and robotized, while management is based on artificial intelligence and big data. These facilities operate continuously—24/7, year-round—without human involvement, significantly increasing efficiency by eliminating costs associated with human error, labor, and energy consumption. For example, technological capabilities enable production speeds of up to one smartphone per second (e.g., Xiaomi). This trajectory of industrial digitalization is actively supported across advanced industrial economies.

According to the China Academy of Information and Communications Technology, the scale of China's digital economy continues to expand annually; however, the pace of digital transformation remains uneven across sectors. The highest level of digital penetration is observed in services (44.7%), followed by industry (24.0%) and agriculture (10.5%) [Zuo, 2025].

All programmatic documents on technological modernization are embedded within a broader strategic objective: achieving and consolidating China's global leadership in advanced technologies. Within this overarching framework, a range of complementary policy initiatives has been adopted. Notably, in 2015, the industrial policy strategy "Made in China 2025" was introduced, aimed at reducing dependence on foreign technologies and promoting Chinese high-tech manufacturing globally. Within this strategy, the objective of developing "intelligent manufacturing," based on the integration of internet technologies into industrial production, was first formally articulated [10-13].

II. Methodology

Within the framework of this study, the digital economy was theoretically substantiated and analyzed. Based on the developed methodology, its level of development was assessed, and the impact of the digital economy on the rate of technological convergence was evaluated. In addition, practical recommendations for the formation of a digital economy in the Republic of Azerbaijan were developed and justified.

The relevance of the problem is determined by its high socio-economic importance for the Republic of Azerbaijan, which also conditioned the selection of the research topic and the need to elaborate practical recommendations for the formation and development of the digital economy within the global economic system.

A comprehensive methodology for calculating the Composite Digital Economy Development Index (DI) has been proposed. This methodology assumes an assessment of digital economy development based on a broad system of indicators and enables an objective analysis across five key dimensions. To ensure comparability of indicators expressed in different measurement units, a normalization approach is applied: each variable is linearly transformed into a score within the interval from 0 to 1, where 1 corresponds to the maximum value (the higher the score, the higher the level of "digital development"). This is expressed by Formula (1):

$$Y\ (X) = \frac{X_i - X_{min}}{X_{max} - X_{min}}, \qquad (1)$$

Here, Xi- denotes the value of the i-th indicator; Xmin -represents the minimum value of the indicator; Xmax -represents the maximum value of the indicator.

Table 1

presents the aggregation of normalized indicators using equal weighting.

Countries	Quality of ICT infrastructure and internet access	Intensity of internet usage	Human capital	Digitalization of the economy	Effectiveness of the digital transformation of the economy	Rİ
Highly developed						
Sweden	0,8141	0,9343	0,6604	0,9138	0,8132	0,8211
Finland	0,6606	0,8944	0,6122	0,9944	0,8902	0,8102
Denmark	0,7710	0,9473	0,7147	0,7730	0,4655	0,7102
United Kingdom	0,8165	0,7734	0,7056	0,8634	0,4640	0,7091
Developing						
Estonia	0,5683	0,8301	0,5384	0,8741	0,5276	0,6526
Czech Republic	0,4228	0,5272	0,4954	0,8073	0,5555	0,5631
Latvia	0,3623	0,7095	0,5931	0,6865	0,4860	0,5563
Germany	0,5384	0,5408	0,6155	0,6779	0,3553	0,5363
Moderately developed						
Hungary	0,2469	0,5845	0,5183	0,7550	0,3796	0,4866
Poland	0,3256	0,4837	0,5650	0,6491	0,2957	0,4544
Romania	0,3263	0,4525	0,1353	0,6160	0,4240	0,3894
Bulgaria	0,2464	0,4308	0,0504	0,6036	0,4562	0,3588
Russia	0,3245	0,2334	0,4571	0,3341	0,3719	0,3511
Insufficiently developed						
Kazakhstan	0,3710	0,1590	0,4732	0,0000	0,0000	0,1927
Azerbaijan	0,2654	0,1348	0,3521	0,0000	0,0000	0,1842

The following formula is proposed for calculating the value of the sub-index (2):

$$Sub - Index = \sum_{i=1}^{n} \frac{y_i}{n}? \qquad (2)$$

Subsequently, the author assigns weights wjw_jwj to each of the five sub-indices, and based on these weights, the overall index is calculated using the following formula (3)

$$Index = \sum_{J-1}^{n} SI_j\, W_j, \qquad (3)$$

where SIj- denotes the value of the j-th sub-index;Wj -is the weighting coefficient of the j-th sub-index; and jjj represents the ordinal number of the sub-index.

Based on the empirical validation of the developed methodology, a comparative analysis of the Republic of Azerbaijan with EU and EAEU countries was conducted. These countries were classified into four groups according to their level of digital economy development: highly developed (RI ≥ 0.7); developing (0.5 ≤ RI < 0.70); moderately developed (0.3 ≤ RI < 0.50); and underdeveloped (RI < 0.3).

It should be noted that in Azerbaijan, the oil industry holds a leading position in the adoption of advanced technologies. According to the Digital Transformation Strategy for other industrial sectors through 2030, adopted in 2021, "industrial digital transformation is a priority area for the development of the national economy, ensuring high adaptability in business model formation and the operation of production processes through the integration of end-to-end digital technologies." [14-16].

Given the emphasis on the use and development of domestic Azerbaijani technologies, it can be argued that the digitalization process in most companies remains at an early stage. Thus, digital transformation represents one of the most pressing challenges for industrial enterprises both globally and in Azerbaijan.

III. Discssion

Phased Formation of the Digital Economy in Azerbaijan's Industrial Sectors: Prior to the advancement of digitalization and digital transformation processes in the global economy, it was widely assumed that only large and mature firms possessed the capacity to effectively access new international markets. In the contemporary context, however, the emergence of global digital platforms (GDPs) as new economic actors has significantly simplified this process, enabling even small enterprises to achieve rapid internationalization and access global markets. On this basis, firms from developing countries have, within a relatively short period, become active participants in international economic relations.

Consequently, both economic globalization processes and the development of GDPs have become key determinants facilitating firms' access to global markets. In essence, the development of GDPs represents both a result and a manifestation of scientific and technological progress over recent decades. At the current stage, digital technologies have become an integral part of everyday life, which has driven the intensive expansion of international online trade and transformed it into a critical component of multinational corporations' (MNCs) foreign economic strategies.

The Fourth Industrial Revolution has stimulated the emergence of new technologies aimed at enhancing the international competitiveness of national economies worldwide. In this regard, traditional business tools and models are gradually being replaced by digital business processes, making the continuous adaptation of MNC strategies an essential requirement.

At the same time, under the influence of economic globalization, international competition in digital technology markets has intensified further, and competition between traditional and technology-based multinational corporations (MNCs) has become exceptionally strong. The success of several transnational technology giants (e.g., Google, Apple) demonstrates that they have developed specific competitive advantages in areas such as cloud infrastructure and computing, as well as artificial intelligence (AI) and the Internet of Things (IoT). [17-20].

A new class of companies—technology multinational corporations—operate through various types of global digital platforms (GDPs), including transaction platforms, peer-to-peer sharing platforms, and others. In essence, GDPs are considered an emerging and promising model of international business, as online channels significantly facilitate access for small and medium-sized enterprises (SMEs) and consumers to a wide range of service providers. Possession of large tangible assets is no longer regarded as a necessary condition for entering global markets.

The growth rates of the GDP market are unprecedented. However, from a theoretical perspective, the phenomenon of GDPs remains insufficiently studied: stable conceptual frameworks, classifications, and regulatory instruments have yet to be fully developed. At the same time, many multinational corporations operating in the information and communication technology (ICT) sector are increasingly specializing in the provision of various information services delivered on global markets. Such MNCs implement highly aggressive competitive strategies in international markets, resulting in a sharp increase in their profitability and capitalization in recent years.

The strategies of these corporations are focused on product and service diversification, while their international specialization is increasingly shaped by the exchange, management, and dissemination of data (information). Considering the main global economic trends and current technological developments, Russia does not fully exploit the potential of the digital economy, although the transformation of business processes in domestic companies has accelerated in recent years. Nevertheless, numerous challenges remain unresolved in relation to the modernization of industrial business processes, the development of high-tech production sectors, and the involvement of global digital platforms in these processes.

In this context, the application of advanced international experience of foreign multinational corporations (MNCs) in digital transformation and the formation of technological competitive advantages is of particular importance for the country.

The development of new business models of technology-based MNCs remains insufficiently explored in the economic literature. The economic dynamics of the modern global economy are undergoing profound changes under the influence of digital transformation, and this process, in our view, is accompanied by deep structural shifts in both consumption and production sectors. As a result, new types of goods and services emerge, while the operational practices, business models, and corporate strategies of firms of all sizes are being transformed.

Based on the experience of leading countries in stimulating digitalization in Azerbaijan's industrial sectors, and through the integration of efforts by the state, science, and business, the following key directions can be identified:

1.Legal support for the transition to a digital economy (development of a regulatory framework corresponding to a new model of interaction between the state, scientific organizations, business, and society in the digital environment, including the improvement of legislation related to the application of automation, robotics, and artificial intelligence technologies);

2.Implementation of digital technologies in public services (based on the "single window" principle);

3.Digitalization of the real sector (Industry 4.0 and precision agriculture);

4.Digital transformation of the banking sector;

5.Development and strengthening of modern information and communication infrastructure (4G, 5G);

6.Human capital development (digital skills and competencies);

7.Ensuring cybersecurity (prevention of cyberattacks and cybercrime);

8.Ideological support for the transition to a digital economy (the concept of an "IT-country").

These measures will enable the transition in the Republic of Azerbaijan to digital governance of the state and economy based on a unified intelligent

knowledge system, advanced information technologies, and specialized software complexes. This, in turn, will serve as an important factor in addressing existing socio-economic challenges in the country, while also creating conditions for improving the efficiency of the public administration system and implementing necessary reforms in education, science, and the economy.

From the perspective of their impact on the development of the global economy and society, the key technologies underpinning the digital economy—namely blockchain, cloud computing, big data, the Internet of Things (IoT), and cyber-physical systems—have been analyzed. The application of these technologies generates the following positive economic and social effects:

– automation and intensification of traditional economic and technological processes, as well as the emergence of new economic sectors;

– improvement of the business and investment climate through increased accessibility and efficiency of public services and enhanced transparency of the business environment;

– increased accessibility, quality, and convenience of healthcare, education, cultural, and financial services for the population;

– development of livable and safe urban environments.

It has been identified that among the risks and threats associated with the digitalization of the economy and society, significant social risk arises from the structural transformation of the labor market and potential reductions in employment. In addition, the spread of new forms of criminal activity, particularly cybercrime, poses a serious threat.

It has been substantiated that the widespread adoption of digital technologies has significantly contributed to the formation of a new stage of globalization—digital globalization.

It has been determined that, at present, digital data and information flows possess significant economic value, as they facilitate the movement of goods, services, financial resources, and people, and exert a stronger impact on global GDP growth than international trade and cross-border capital flows. In the context of digital globalization, the processes of information production, distribution, cross-border exchange, and consumption occupy a dominant position compared to other types of economic activity, thereby reinforcing the virtualization of the economy. As a result, a new system of organizing economic relations is emerging—a global digital economy characterized by its own regularities and development patterns.

At the current stage, one of the key challenges in the field of artificial intelligence is the explainability and transparency of its "reasoning processes." This issue can be considered a matter of global security, despite the fact that artificial intelligence is currently predominantly applied at the local level.

The digital transformation of an organization presupposes the creation of a digital platform. This requires the formation of a high-level expert capacity within the organization in this field. The availability of highly qualified personnel covering all competencies required for the implementation of complex IT business projects is essential. These include:

- digital transformation managers;
- project managers;
- domain consultants and business analysts;
- software developers (1C, Web, and Power BI);
- data engineers;
- system administrators.

A digital platform is a set of interoperable software products that provide the core functionalities required for the development of business applications. Such a platform enables the rapid design and deployment of new business applications, while also ensuring their efficient maintenance and continuous improvement [21].

The platform integrates widely used software solutions familiar to both end-users and technical specialists and, at the same time, is characterized by an open architecture that allows seamless integration with any other software solutions.

Conclusions

1.In the context of contemporary globalization, a theoretical approach to the digital economy as an independent phenomenon has been substantiated. This approach covers the following aspects: the delineation of the digital economy from other concepts of the modern global economy that are closely associated with distinct ICT development trajectories; the clarification of the content of the concept of "digital economy"; the identification of the causal relationship between the widespread diffusion of digital technologies, the transition from the fifth to the sixth technological paradigm, and the transformation into the Fourth Industrial Revolution; the assessment of both the positive effects and risks of digitalization; and the differentiation of stages of digital economy development, including digital globalization as a new phase of globalization.

The analysis demonstrates that digital technologies are extensively applied not only in traditional economic and financial sectors but have also penetrated education and healthcare systems, as well as public administration and service delivery (e-government), becoming one of the key global trends in recent years. The practical application of digital economy technologies significantly influences consumer behavior, enhances firms' flexibility in continuously improving product and service quality, increases labor productivity, and contributes to sustained improvements in population welfare.

Digital globalization acts as a driving force of global economic growth and creates new business opportunities for firms, including unrestricted access to the best suppliers, customers, labor resources, and financial sources; the ability to conduct "borderless business" in real time; reduced operational, marketing, and customer interaction costs in new markets; the organization of virtual teams through digital platforms; and the transformation of small enterprises and startups into multinational corporations from the earliest stages of development.

2.An assessment of the level of digital economy development across countries has been proposed using

the Digital Economy Development Index (DEDI) developed by the author. This index is composed of five sub-indices characterizing the key dimensions of the digital economy: the quality of digital infrastructure and ICT access, intensity of internet usage, human capital, digitalization of the economy, and effectiveness of digital transformation. This approach enables a comprehensive evaluation of a country's position in global digital development.

The DEDI calculations conducted for 16 EU and EAEU countries, including the Republic of Azerbaijan, allowed the classification of the studied countries into four groups: highly developed, developing, moderately developed, and underdeveloped.

The results confirm a high level of digital economy development in Sweden, Finland, the United Kingdom, and Denmark. It has also been established that a high level of digital economic development is closely associated with factors such as the quality of digital infrastructure and ICT access, intensity of internet usage, level of human capital development, degree of economic digitalization, and effectiveness of digital transformation. Digital transformation processes have been identified as a key determinant that enhances the efficient use of production factors, stimulates economic growth, strengthens competitive advantages in domestic and international markets, and fosters innovation.

The Republic of Azerbaijan has been classified among the group of "developing countries" (DEDI = 0.5003). The country demonstrates below-average performance in terms of digital infrastructure quality and ICT access, near-average indicators in internet usage, economic digitalization, and digital transformation effectiveness, and above-average performance in human capital development. This has made it possible to identify key challenges in the development of the digital economy and to formulate recommendations aimed at improving the country's international digital ranking.

3.A model has been proposed to assess the impact of a country's position in the global digital economy on the potential growth of total factor productivity. This model is based on the use of the previously developed Digital Economy Development Index (DEDI) for calculating the Technological Convergence Conditions Index. It has been demonstrated that digital transformation exerts a direct effect on economic growth, depending on the quantity and quality of accumulated human and digital capital. It has been determined that the growth rate of the technological progress factor significantly depends on the efficient utilization of a country's digital potential, its capacity for rapid scaling, and the speed of adoption of scientific and innovative advances. This approach indicates that Azerbaijan's GDP can increase primarily through capital accumulation, innovation, and digitalization. In the long-term perspective (2030–2050), the potential annual economic growth rate may reach 4.5%.

4.The issue of improving industrial production efficiency has become one of the key priorities for the Azerbaijani market. In the context of intensifying competition and the imperative of technological sovereignty, enterprises are increasingly confronted not merely with the need to modernize equipment, but with the challenge of establishing an integrated production management system—ranging from process standardization to the implementation of digital solutions.

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TRADE WARS AND THEIR CONSEQUENCES FOR THE GLOBAL ECONOMY

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Abstract

With the development of international trade, the number of conflicts also increases, leading to significant losses for its participants and complications in interstate relations. In this context, there arises a need for measures to regulate international economic relations, including mechanisms that allow for the prevention and effective resolution of emerging conflicts with minimal costs.

The aim of this work is to analyze the characteristics of modern international trade development amid intensified competition and the formation of international mechanisms for resolving conflicts in the global market, in order to provide a more complete understanding of the potential use of these mechanisms to protect the interests of domestic exporters and importers, as well as producers and consumers of goods and services.

The novelty of this research lies in clarifying the depth of the economic and trade-political reasons for the increase in conflicts in the global market in the second half of the 20th and early 21st centuries, in applying a comprehensive approach to the problem of conflicts, and in filling gaps in the study of multilateral regulation of international trade.

Keywords: trade wars, international trade, economic instability.

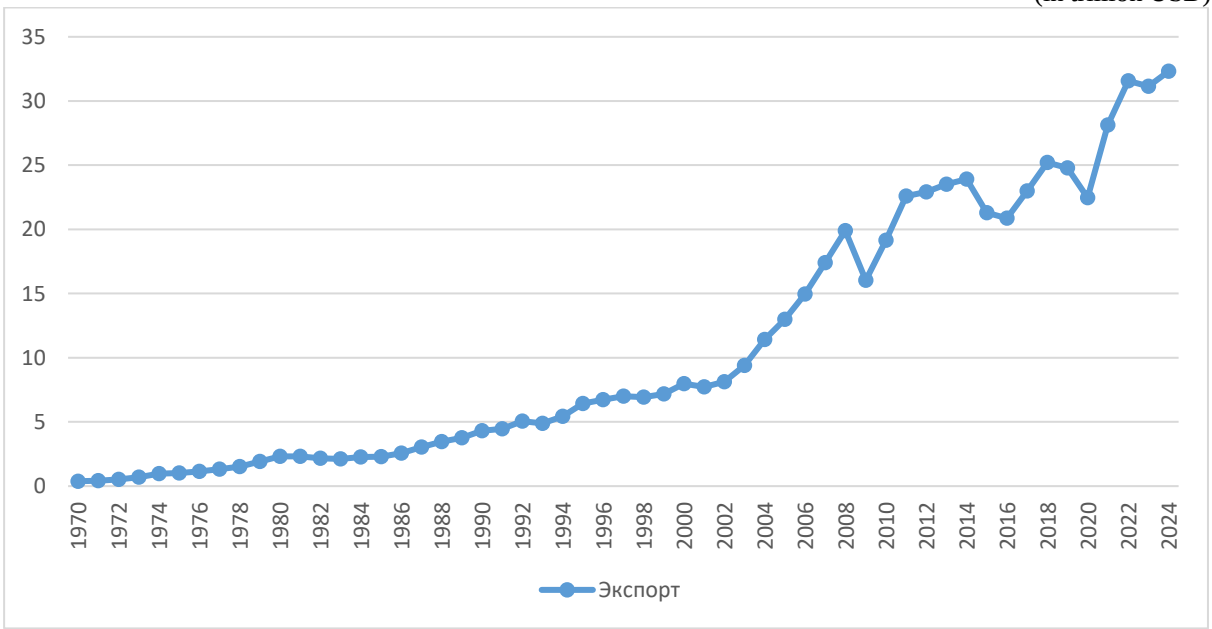
Conflicts in foreign trade are a significant negative factor for the development of international economic relations. The damage from such conflicts increases primarily with the rise in their number and the value of contracts, and particularly with the implementation of various trade-political measures aimed at unjustified restrictions on trade or unlawful strengthening of suppliers' positions in the global market. These aspects in the development of modern trade—specifically the causes of disputes, their scale, forms, economic consequences, and, most importantly, ways of resolution—have not been sufficiently analyzed. At the same time, trade conflicts damage mutual cooperation not only among the immediate participants but also among national economies, and therefore naturally attract growing attention from the global community.

The development of world trade is accompanied by conflicts between its direct participants, between counterparties and official institutions of other countries, and in relations between governments. In the second half of the 20th century, these conflicts intensified significantly for many economic and trade-political reasons and became a factor complicating international cooperation.

Figure 1

Development and Changes in the Structure of Global Exports, 1970–2024

(in trillion USD)



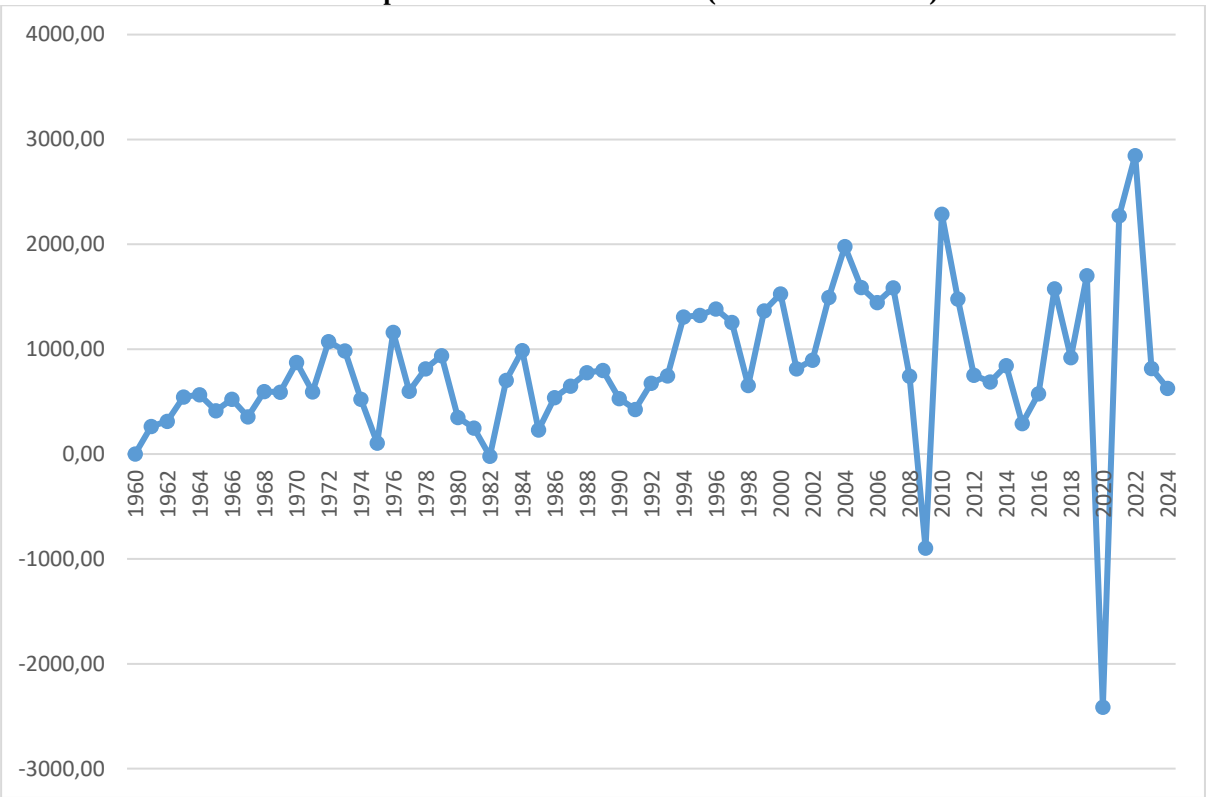
One of the objective reasons for the growth of conflicts in foreign trade is the rapid increase in the scale of global exports (Figure 1). World exports grew more than 80-fold between 1970 and 2024. The average annual growth rate of global exports during this period exceeded 5% and was significantly higher than the corresponding rate of growth of the total gross product of all countries.

Another similar reason for the increase in conflicts in foreign trade is the change in its commodity structure in favor of manufactured goods.

Trade in services, previously considered only a component of goods trade, has in the last two decades come to be regarded as an independent sphere of international economic relations and has also grown significantly. In the 1970s and 1980s, the growth rate of global service exports outpaced that of goods exports, and in the 1990s it grew at similarly high rates as goods exports (Table 2).

Table 2

Global Exports of Goods and Services (Annual % Growth)



Source: data.worldbank.org

Statistical indicators of the annual growth rate of global exports of goods and services from 1960 to 2024, shown in Figure 2, are characterized by high volatility, reflecting both economic cycles and global crises affecting international trade. The figure shows that the world economy actively recovered after World War II, with stable positive growth averaging 6–8% per year. This growth was driven by the industrialization of Europe and Japan, as well as the expansion of world trade under GATT.

The period from 1974 to 1985 saw sharp fluctuations, caused by oil crises, inflationary shocks, and recessions in various countries. During this time, export growth slowed to 2–3% per year. Beginning in 1986, the global economy entered a period of sustained growth. This stability was supported by the development of international trade agreements, the expansion of production chains in Asia, and the establishment of the WTO in 1995. However, attention should also be paid to the Asian financial crisis of 1997–1998, which caused a brief downturn followed by recovery.

A global economic boom occurred between 2001 and 2008, with exports reaching record growth rates, especially in China. The curve in Figure 2 rises to nearly 3,000% (relative changes axis). A sharp decline is then observed in 2008–2009, linked to the global financial crisis, marking the steepest drop in exports over the entire period. In 2009, growth turned negative, representing a near collapse of the world economy. This was followed by uneven recovery, with alternating periods of growth and decline until 2019. These fluctuations allowed exports to grow at moderate rates, influenced in part by trade wars between the USA and China.

In 2020, the year of the COVID-19 pandemic, recovery began and has continued to the present. By 2024, global exports had increased by only 3–4%, significantly below the average growth rates of previous decades.

Another emerging and highly contentious area in international economic relations has become trade in intellectual property.

The development of world trade in the second half of the 20th century was characterized by a significant increase in volume and the expansion of participating countries (Tables 3–5). Increased competition changed

the positions of individual states in the global market, intensifying relations between direct suppliers and national governments.

Table 3

Exports of Goods from Major Developed Countries (in billion USD)

Страны	1946 г.	2000 г.	2001 г.	2003 г.	2010 г.	2015 г.	2020 г.	2025 г. (прогноз)
США	9,5	782	730,9	724,0	1 279	1 419	1 431	~1 600
Франция	0,9	298	319,5	384,7	474	510	490	~520
Великобритания	3,7	280	273,5	303,9	560	630	695	~710
Канада	2,2	277	262,2	272,1	430	448	450	~480
Всего в мире	31,7	6180	6162,4	7274,0	16 718	18 181	22 483	~24 000

By 2003, compared to 1946, the share of several of the most developed countries in global exports had decreased significantly: the USA – from 30% to 10.0%, the United Kingdom – from 11.7% to 4.2%, and Canada – from 6.9% to 3.7%.

Among developed countries, Japan expanded its exports most dynamically. It managed to noticeably displace major competitors and substantially increase its share of global exports (9% in 2000). Only in the last decade did Japan's share slightly decline (to 7.7% in 2000) due to economic stagnation and the expansion of capital exports to establish assembly production abroad, directly in sales markets, thus circumventing various trade barriers. However, by the 2010s, the share of goods exports began to fall to 7.8%, associated with economic stagnation, relocation of production overseas, and competition from Asian countries. Specifically, Western European countries began adopting Japan's approach and, more recently, have also been actively expanding production abroad.

In the period 2010–2015, there was post-crisis growth following the global financial crisis. According to Table 3, in 2015 the USA achieved goods exports of up to $1,431 billion due to the development of high-tech and energy exports. Japan maintained its volumes, with moderate growth due to weak domestic dynamics and strong competition with China and the Republic of Korea. France and the United Kingdom continued to lead in exports of industrial goods and machinery. Nevertheless, during this period the United Kingdom faced currency fluctuations.

In the period 2016–2020, goods exports were persistent but fluctuated due to trade restrictions and customs disputes. The COVID-19 pandemic in 2020 caused a decline, with exports in these countries decreasing by 10–15%. However, the EU countries weathered this period steadily, as their system of mutual supplies mitigated the economic impact.

After 2021, the global economy experienced a surge. By 2024, its volume reached $32–33 trillion. In 2025, according to forecasts, growth is slowing due to geopolitical conflicts and high inflation, but there is a shift in favor of developing countries.

Table 4

Exports from Developing Countries and China, 2001–2024 (in billion USD)

Country	2001	2003	2015	2024
China	266,2	438,4	2542	3356,3
Mexico	158,5	165,3	414,5	681,5
South Korea	150,7	194,3	630,2	683,1
Singapore	121,7	144,1	549,4	978,6
World Total	6162,4	7274	18130	24,43 tr

Among the group of countries under consideration, China should be highlighted, which accounted for 4.0% of global exports in 2000 (4.3% in 2001, 6.0% in 2003). Its share increased particularly sharply over the last decade, prompting countermeasures in many importing countries. After 2015, growth rates slowed, but the country still held a leading position in goods exports; over more than 20 years, its exports increased 12.6 times.

Among developing countries that increased their share of global production, Mexico stands out (growth of almost 4.5 times compared to 1953, mainly due to assembly production) and the countries of the Middle East (due to increased oil supplies and rising prices). From 2015 to 2024, growth accelerated due to the relocation of production chains from China.

At the same time, many developing countries, many of which were former colonies, had no experience either in commercial practices or in state trade regulation. This also increased the level of conflict in the global market.

Table 5

Changes in Positions of Developed and Developing Countries in Global Exports, 1953–2022 (%)

	1953	1973	1983	1993	2000	2003	2022
Region/Country	100,0	100,0	100,0	100,0	100,0	100,0	100,0
North America	24,2	16,9	15,4	16,8	17,9	15,8	13,3
Western Europe	34,9	45,4	38,9	43,7	39,5	46,2	35,8
Japan	1,5	6,4	8,0	10,0	7,7	6,4	4,0
Australia & New Zealand	3,2	2,1	1,4	1,5	1,2	1,4	1,54
China	1,2	1,0	1,2	2,51	4,0	7,7	14,2
Mexico	0,7	0,4	1,4	1,4	2,7	2,4	2,15
Middle East	2,7	4,1	6.8	3,4	4,2	2,5	2,9

Changes in the positions of countries in global exports are driven by shifts among suppliers in certain relatively large commodity markets, in particular ferrous metals, chemical products, and machinery and equipment (Tables 6, 7, and 8; the WTO Secretariat provides the corresponding statistical data only for the last two decades of the 20th century).

Table 6

Changes in Positions of Major Suppliers in the Global Ferrous Metals Market, 2005–2015 (%)

	2005	2010	2015
Japan	9,9	7,8	6,5
Germany	4	3,1	2,6
France	4,2	1	0
Italy	3,3	1,8	1,4
USA	8,2	5,6	4,8
Sweden	0,52	0,33	0,28
South Korea	4.2	4,1	4,3
China	30,9	44,3	49,5

The positions of the Republic of Korea (whose share more than doubled) and China (over the last decade of the 20th century) have significantly strengthened in the global ferrous metals market, whereas Japan, the main supplier, saw its share drop sharply. Between 2005 and 2015, the share of Western European suppliers also declined due to restructuring and reduction of production capacities. It should be noted that exporters of ferrous metals (and chemical products) are most frequently subject to investigations, both justified and unjustified, for alleged unfair commercial practices, aimed at restricting their access to domestic markets.

In 2020, global crude steel production totaled 1,864 million tons, with China's share increasing noticeably to 56%. Unfortunately, after the pandemic, this figure decreased to 53% by 2024. These numbers indicate that China has effectively absorbed available market shares and has become dominant, displacing many traditional leaders. This trend shifts the global ferrous metals industry toward Asia, signifying growth and development of the region's infrastructure. Consequently, European and American players are losing shares in the global market, as can be seen in Table 6.

Table 7

Changes in Positions of Major Suppliers in the Global Chemical Products Market, 2005–2015 (%)

	2005	2010	2015
USA	24,4	16	12
Germany	12,6	10,1	9,3
France	5	13,6	9,9
Japan	8,6	7,8	4,6
UK	3,2	1,9	1,1
Netherlands	2,9	2,2	2,0
Sweden	2,0	1,0	0
South Korea	3,0	5,5	2,8
China	10,8	25,8	37,2

On the global chemical products market, the positions of developed countries such as France and Japan have strengthened significantly, while among developing countries, the Republic of Korea and China have also expanded their shares. At the same time, Germany, the Netherlands, and the United Kingdom have seen a substantial decline in their share of global exports. The share of the United States, a leading supplier, has remained at the same level.

Changes in the positions of various exporters in individual product markets were accompanied by corresponding protective measures from competitors, which, in turn, served as an additional source of trade-political conflicts.

In developed countries, with government support, small and medium-sized enterprises (SMEs) were involved in foreign trade; these companies often operated

using the latest technologies, became narrowly specialized, and targeted specific consumers. While competitive, these enterprises were newcomers in practical operations on the global market and frequently found themselves in conflict situations due to inexperience or even initiated them.

For example, exports from SMEs in EU countries increased in the 1980s and 1990s at rates exceeding the growth of total turnover and GDP. Annual export growth for these companies exceeded 4% (micro-enterprises, i.e., companies with up to 9 employees, almost 5%), while the corresponding turnover and GDP indicators slightly exceeded 3%. As a result, the share of SMEs in the export of goods and services of EU countries combined nearly reached 40% in the 1990s, including micro-enterprise contributions exceeding 10%.

The contribution of more than 100,000 SMEs in the United States to national exports approached 30%, with companies having up to 20 employees contributing 12%, those with up to 99 employees 8%, and those with up to 500 employees 9%.

Postwar tariff liberalization of international trade, occurring at multilateral, regional, and bilateral levels, stimulated foreign trade expansion for entrepreneurs and state support for their activities in external markets. The downside of these processes was an increase in trade conflicts.

Finally, the high profitability of foreign trade operations under insufficient regulation encouraged entrepreneurs to engage in various abuses and unfair commercial practices, creating yet another major source of conflicts in the global market.

Trade-political conflicts, which primarily arise between governments, ultimately affect the interests of major entrepreneurs in the conflicting countries or their groups. These may be entrepreneurs in specific industries or across multiple industries, when measures to restrict or promote trade are unjustifiably applied to them. In both cases, the damage from a single trade-political conflict is usually very large and disproportionate to that from a commercial conflict.

Among the sharpest sectoral trade-political conflicts in the 1990s was the dispute between the United States and the Republic of Korea regarding mutual automobile supplies, the production of which in both countries is a key industrial sector (Korea exports up to 1.5 million vehicles annually, ranking 6th globally). By threatening sanctions, the United States sought (and partially achieved) non-tariff liberalization of the Korean domestic market concerning taxation, standards, and processing of import transactions (customs duties on imported cars in Korea were lower than in most OECD countries) [4].

While commercial conflicts between partners generally result only in additional costs, trade-political conflicts often lead to supply stoppages. Such situations are especially common with anti-dumping measures, which often result in high, effectively prohibitive import duties. Cases also occur where exporters suspend shipments during anti-dumping investigations, even when no unfair competition is confirmed.

The inevitability of trade-political conflicts, with all their adverse economic consequences for many countries, is sometimes due to the “integration” into national legislation of the right to arbitrarily apply protectionist measures [1].

It is also necessary to mention a specific conflict between the EU and the United States, triggered in early 2000 by the EU’s discovery of American commercial espionage against European competitors using the global Echelon intelligence network (originally created during the Cold War for conventional espionage against former socialist countries). Information obtained through it (intercepted international phone calls, telex and fax transmissions, emails, satellite, microwave, fiber-optic, and mobile communications) served the interests of US companies very effectively.

Commercial conflicts manifest in many forms and affect the interests not only of entrepreneurs but also of states.

Primarily, commercial conflicts negatively impact the direct participants in trade transactions. An exporter does not receive the agreed payment in full or on time if the partner fails to fulfill contractual obligations. Importers, in turn, do not receive the agreed quantity of goods (or services), or the quality is below contract standards. Both parties also incur additional costs, such as legal fees.

Since a significant portion of foreign trade operations is conducted with bank credit, banks do not receive expected profits or timely repayments in the event of contract nonperformance.

Moreover, given the close connection of many foreign trade operations with the activities of enterprises, sometimes large industrial complexes, even a single failure in commercial relations can cause substantial damage to the production of such enterprises and complexes.

Finally, commercial conflicts harm the state in the form of delayed tax revenues, fees, and similar payments. If a state-owned enterprise is involved in a conflict, it suffers like any other exporter or importer.

As trade conflicts spread, the damage they cause also increased. Therefore, joint actions by the global community at governmental and non-governmental levels gained importance for preventing conflicts and resolving them when disputes arise.

Since WTO members adopted the Agreement on Rules and Procedures Governing the Settlement of Disputes, relatively little time has passed, yet some preliminary conclusions can already be drawn. Overall, these outcomes can be considered positive. Many WTO members turn to the dispute settlement mechanism, with a significant number of conflicts resolved at early stages (especially consultations), and in all cases, conflicts were ultimately settled.

According to a report prepared by the WTO Secretariat for the first Ministerial Conference of WTO members (as of November 26, 1996), 62 disputes had been considered, were under consideration, or were in the process of implementation of adopted decisions. By 2004, the total number of complaints submitted to the WTO reached 304.

Since the WTO's creation until the first Ministerial Conference, all instruments of the dispute settlement mechanism were utilized, although to varying degrees.

The most effective tool for reaching mutually acceptable solutions without burdening other instruments was consultations. At this stage, 60% of disputes were resolved (by 2001, this figure reached 75%). The effectiveness of consultations was confirmed further. From 1995 to June 2003, special panels were formed only 110 times (out of 261 complaints), demonstrating the possibility of dispute resolution during consultations.

It is noteworthy that developing countries continued to account for a high share of dispute mechanism usage. According to WTO Secretariat data, in 2001, they filed 2/3 of all complaints. From January to June 2003, their share among claimants was 42%. US and EU participation in using the WTO dispute mechanism in 2000–2003 was mainly due to complaints filed against them by other WTO members.

A parallel investigation by the US General Accounting Office revealed several practical aspects of WTO activities. Member countries are obliged to notify the Secretariat of all changes in their national trade regimes. From 1995–2002, 1,405 notifications were received, including 239 from the US. Of these, 64 notifications were contested, i.e., complaints were filed regarding unlawful changes causing damage, with the highest number involving the US (see Table 13).

The relatively lower involvement of the EU in dispute resolution for a long period is explained by its own internal mechanism among member states.

These data indicate that WTO members, both developed and especially developing countries, actively use the organization to resolve trade regulation disputes.

Despite the effectiveness of the WTO dispute settlement mechanism, member countries pay considerable attention to its improvement.

At the fourth WTO Ministerial Conference in Doha, Qatar, November 2001, a declaration was adopted, including a three-year work program. This program contains a section "Understanding on Dispute Settlement," agreeing to conduct negotiations to improve the dispute resolution mechanism. Unlike the general schedule of a new WTO negotiation round (from January 1, 2005), the dispute settlement negotiations had tighter deadlines—May 2003—to implement results as soon as possible.

The GATT trade-political conflict resolution mechanism underwent a long development, with amendments related to changes in the global economy, primarily the expansion of participants in international economic relations and the growth of exports of finished and semi-finished goods. In addition, the experience of cooperation and compromise among GATT members accumulated.

The purpose of the improved dispute resolution mechanism is to protect the economic interests of WTO members and ensure their compliance with obligations arising from the covered agreements. Research shows that this goal is largely achieved. The rules and procedures also apply to trade agreements among a limited number of participants.

General conclusions:

- In the second half of the 20th century, the international community created an effective system for preventing and resolving conflicts, consisting of two mechanisms: for commercial and trade-political conflicts;
- The updated trade-political dispute mechanism provides all WTO members equal opportunities to resolve conflicts within a strictly regulated period;
- WTO members actively use this mechanism, especially developing countries, to protect their interests from trade-political arbitrariness, including that of developed countries;
- Consultations and special expert panels confirm the effectiveness of the rules of the Dispute Settlement Understanding;
- WTO bodies review disputes objectively and professionally, as publicly confirmed by the US General Accounting Office in 2003.

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Trade wars and their consequences for the global economy

As international trade develops, the number of conflicts increases, resulting in significant losses for participants and complicating interstate relations. This necessitates measures to regulate international economic relations, including a mechanism to prevent and effectively resolve emerging conflicts with minimal costs.

The purpose of this paper is to analyze the development of modern international trade in the context of intensifying competition and the emergence of international conflict resolution mechanisms in the global marketplace. This aim is to provide a more comprehensive understanding of the potential for using these mechanisms to protect the interests of domestic exporters and importers, as well as producers and consumers of goods and services.

The novelty of this study lies in its understanding of the underlying economic, trade, and political causes of the increased conflict in the global marketplace in the second half of the 20th and early 21st centuries, its comprehensive approach to the problem of conflict, and its filling of gaps in the study of multilateral regulation of international trade.

JURISPRUDENCE

SOME ASPECTS OF THE INFLUENCE OF MORAL AND LEGAL VALUES ON THE FORMATION AND DEVELOPMENT OF THE POLITICAL-LEGAL SYSTEM

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Abstract

The political and legal systems of any society, in their formation and development, reflect the process of tension, exploration, effort, and struggle of humanity's spiritual and physical forces. Relying primarily on the moral and ethical values created by humanity, political and legal systems are rooted in the interests, needs, and requirements of society's members and can achieve their socialization and a conscious attitude toward state and legal processes. Moral values, seeping from the depths of society, permeate all its other subsystems; they not only rise to the level of politics and law, but also rise above them as the highest of all existing universal human values. The article examines the problem of values in the moral and legal context, reveals the importance of moral values in the progress of society and draws attention to some aspects of their influence on the formation and development of the political and legal system.

Keywords: moral and spiritual values, political and legal system, moral norms, legal priorities, political and legal institutions, freedom, equality, justice, humanism, ethical code.

Every political and legal system, as well as political and legal culture, is formed on certain values. The analysis of values, ideology, and ideological foundations of law and politics contained in legal science and legislation is considered important in terms of clarifying the essence of the processes taking place today and determining new directions of development. Customs, formed in the early stages of society's development and aimed at regulating relationships between people, including between fellow tribesmen or representatives of different tribes, gradually evolved into an important system of rules and norms of behavior, reflecting social and legal requirements regarding people's behavior, their attitudes toward other people and toward society as a whole, as well as acceptable actions.

Moral norms formed within the framework of these requirements have a significant impact on the socio-political and legal life of society. At the same time, the existing moral norms and principles, normative and value-based ideas themselves are constantly being reformed in accordance with public opinion, the habits of members of society and their assessments of certain issues. Moreover, moments that took place in various historical periods and were capable of forming the basis of national progress are once again revived in memory and, reflected in people’s behavior, lead to a fundamental shift in socio-political, moral and legal relations. All of this, taken together, determines the main directions of development of society as a whole and its natural activities [Ismayilov, 2016].

It should be noted that the principle of "everything not prohibited by law is permissible", which includes the subordination of all aspects of human relations to legal norms and became popular in the late 1980s and early 1990s, is still referred to today and is still treated the last democratic truth in force. Indeed, at first glance, it clearly meets the requirements of a rule-of-law state, emphasizing the rule of law. However, in practice, such an approach leads to error, arbitrariness, and abuse. Because a rule-of-law state itself cannot ignore the moral and ethical aspects of people's lives, and it is precisely these moral postulates that underlie the legal regulations themselves. If current legislation is not sanctified by the principle of justice—a moral principle—then its enforcement will be problematic.

The belief that anything that should not be prosecuted and punished from a legal perspective is permissible is a widespread illusion that moral values do not exist at all. The price of this is the development of a disdainful attitude toward legislative acts based on "political expediency" or "personal" interests. Political and legal norms that deviate from moral values inherently lead to political and legal nihilism. In this regard, it can be said that in all human relations that develop in civilized societies, including political and legal relations, moral foundations, although invisible, exist and play a role. Moreover, they not only exist, but are periodically put forward during discussions of a particular legal norm or political decision.

Political and legal ideas cannot transcend moral imperatives and must always, to some extent, conform to and align with them. Both power and the state in their political and legal aspects receive justification and recognition from the point of view of the moral ideals prevailing in society; otherwise, they become illegitimate and intolerable. For example, the "right" to suicide and euthanasia will never be legitimate until it receives a detailed moral justification and justification. Likewise, the death penalty and the controversy surrounding it are connected with the difficulties of justifying it from the point of view of modern moral de-

mands. However, this form of punishment was positively perceived by society in the Middle Ages and was widely used in practice; people even regarded public executions as theatrical spectacles. In the modern era, as a result of a fundamental change in the cultural and civilizational situation, public demonstrations of executions, scenes of murder in real life, and their observation are assessed as a bad and unworthy act. Of course, the exception is viewing staged murder and execution scenes—in films and theatrical productions [Ismayilov, 2014; Ethical thought: modern research, 2009].

With the rise of culture and the development of civilization, we can also observe a significant shift in our current understanding of what is morally permissible. Changes in moral values occur as a result of individuals' interactions with social realities and are manifested in their behavior, ideals, principles, and goals. Since these values act as integral parts of people's thinking, we also observe an interdependence between ingrained values and subsequently acquired ones—that is, value concepts that have penetrated society through the reinterpretation of previously existing ones or under the influence of other cultures.

While it is not entirely clear to what extent this manifests itself in political and legal reality, it is certain that the internal connection present in virtually all commonly encountered and universally recognized political and legal systems will be strengthened by moral norms. This means that voluntary and free notions of what is proper and improper, valuable and worthless, formed before the relevant time, can exert a much greater influence on political and legal norms than they do today. For example, in the political life of our country, one can observe that some of those who have the right to participate in elections still treat this right with disdain. Some cite a lack of faith in the possibility of influencing public policy through elections, as well as the fact that a significant portion of elected officials seek to advance their own personal interests and gain privileges. Such views can be overcome through an increase in political and legal culture and the development of an organized civil society—a bearer of stable moral values—which will result in changes in the ideology and psychology of the public as a whole.

In our time, among the issues attracting attention as an object of research, one of the important places is occupied by the study of law, legal thinking, problems of lawmaking, and the moral foundations of the legal system. Rethinking the essence of law, building a regulatory framework on national and moral values, basing political and legal development on moral and ethical roots, and improving political and legal institutions are highly commendable and have enormous scientific and practical significance. As evidenced by the results of sociological surveys conducted in Azerbaijan, despite fundamental changes in the political, legal, social, and economic systems, legal and political issues in national legal consciousness remain closely linked to moral and ethical concerns. Values such as human rights and freedoms, individualism and others are perceived and interpreted not so much in rational-logical and practical aspects, but in a moral dimension.

In the theory and philosophy of law, the nature of moral values is in many cases associated with practical benefits, needs and interests, which is expressed in the reduction of the highest moral-value level to a lower one - psychological, sociological, rational, volitional, socio-economic and even physiological level. The belittlement and distortion of higher values leads to the fact that moral values lose their essence and cannot fulfill the function of a conceptual center that forms the political and legal worldview of society and especially of a particular individual. In this case, the meaning of an individual's existence in the political and legal space is based on such needs and interests as power over others, enrichment by any means possible, achieving success at any cost, boundless egoism, and so on. As a result, the struggle for survival takes center stage, rather than the realization and protection of human rights and freedoms or the building of sincere, harmonious relationships between society and the individual. To eliminate such phenomena that expose society to moral erosion, it is necessary to increase attention to the uplifting, ennobling role of moral and ethical values, to instill their absoluteness, and to constantly promote their undoubted importance in the formation and development of a perfect political and legal system that will lead to the consolidation and progress of society.

When comparing different historical periods, a clear discrepancy in understanding the content and nature of moral and legal values often emerges. Looking back at history, it can be said that the moral and ethical values that had been formed over centuries in the territory of Azerbaijan and in many cases found their expression in various legal acts were transformed during the period of Russian rule due to the systematic nature of the disgusting actions of government officials towards Azerbaijanis. The attitude towards power in that era was not as a goal and a means, but as a right or a privilege, as noted in the materials of that time, “power did not rely on any moral principles and did not act on the basis of any moral force, its representatives neglected freedom of conscience, personal freedom, property rights, instilled only those moral themes that were useful to themselves, but they themselves did not actually follow them” [Alexander II, 1995], - reveals the essence of the political and legal system that was formed in such conditions, which ultimately led to the erosion of moral values.

During the first democratic republic in Azerbaijan from 1918 to 1920, the promotion and protection of individual rights and freedoms, the establishment of social equality, justice, and human freedom throughout society, and the creation of democratic political and legal institutions were rooted in a commitment to moral and ethical ideals and their widespread promotion. This was evident, first and foremost, in the actions of the Republic's leaders themselves. One fact, revealed from archival materials and already well-known in our country, is that the head of the third and fourth cabinets of the Republic, while serving as prime minister, was experiencing financial difficulties and asked his father to send him a sum of money without encroaching on the budget at his disposal, which belonged to the state and the people. This fact testifies to the high level of

morality and ethics displayed by the authorities of that time. For them, the main moral regulator was a sense of responsibility and duty for their actions before other people, as well as before God. It is here that we can see the presence and development of moral components in the political and legal realm. The presence or absence of moral principles in this realm clearly reveals the boundary between politics and politicking.

During the Soviet era, in the 1920s, a spirit of irreconcilable moral relativism and the absence of any moral taboos were characteristic. For example, the thesis proclaimed by the great leader of the Bolsheviks was that if it were possible to deceive even the devil, then it was permissible to ally with the devil himself. Somewhat later, in the sphere of morality, the institution of ideology was formed, expressing coexistence on two fundamental levels – external and internal, incompatible with each other. One of these—the external level—was declarative, that is, in most cases, openly veiled in nature; the other—the internal (real) level—was intended for a limited circle of "insiders," "initiates." For example, while on the surface there was pompous talk of universal equality and the "unity of the party and the people," in reality, privileges of the nomenklatura were growing, bizarre phenomena such as nepotism, parochialism, and cronyism were taking root, and a class mentality was being instilled. In the first years after the collapse of the Soviet Union, in the first years of activity of the newly formed independent republics, a state of moral erosion was also observed, which again found its manifestation in the structure and essence of the political and legal system. As a result, despite the formal enshrinement of freedom and equality for the country's population in the 1990s, we see crimes against property, persons, life, and health, such as racketeering, robbery, theft, and the like, raging, and a large portion of the population suffered from lawlessness and the violation of moral values.

The fundamental political, economic, socio-cultural, and legal reforms implemented in Azerbaijan during the period of independence were aimed at developing the content and expanding the scope of individual and social freedom, and eliminating extreme forms of social injustice and inequality. The establishment of a state governed by the rule of law, the recognition of human rights and freedoms as the highest value, and the ideas of political, ideological, and religious pluralism, enshrined in the Constitution of the Republic of Azerbaijan, legally formalized the eternal universal values of freedom, justice, and equality. At the same time, in almost all monotheistic religious views, formal freedom and formal equality are recognized as values, but humanism, compassion, the obligation to mutual assistance, and human responsibility for those under one's protection, etc., are placed above them.

The values of freedom, justice, and equality, as fundamental principles, manifesting themselves in morality, acquire a moral and ethical character and simultaneously permeate the content and essence of political and legal norms. Various interpretations of freedom exist. For example, the English thinker Isaiah Berlin, who adheres to conservative-liberal views, identified two aspects of the concept of "freedom" – negative and positive. In the negative sense, a subject is free to the extent that no one interferes with their actions. In a positive sense, a person can be considered free when he is his own master, and his life and decisions depend on himself, and not on any external forces [Berlin, 1969].

Understanding freedom as a high degree of personal maturity is fully consistent with moral principles. Indeed, individuals possessing high moral standards are inherently free and have no intention of violating the freedoms of others. Individuals who are politically and legally mature and socialized understand that everyone possesses freedom to the extent that other legal entities are free in their actions. Personal freedom is limited not only by the freedoms of others, but also by restrictions established by law, society, and the state (for example, Part II of Article 28 of the Constitution of the Republic of Azerbaijan).

Natural freedom, on the other hand, means the possession of rights without duties or obligations, that is, the free and unhindered action of an individual based on their conscience and sense of dignity, the ability to do whatever they wish. However, everyone knows that no one possesses natural freedom in society. This is because the laws on which such society is based contain certain restrictions and constraints. In this regard, as M. Speransky noted, in any society there is not complete freedom, but only a degree of freedom, that is, an excess of rights compared to obligations [Speransky, 2001]. From what has been said, it is clear that it is reasonable to accept freedom not as the ability to do whatever one wants, but rather as the highest level of a person’s awareness of his own actions.

Through the mechanism of legal regulation, the problem of conflict and competition between individual freedoms is also eliminated. When establishing rules of conduct, it becomes necessary to incorporate the principle of equality into the practice of social life. Indeed, it is impossible to imagine law without equality. Even in the most imperfect state-legal formations, at least partial equality exists within the population strata, which is extremely important for ensuring the minimal effectiveness of legal systems. It should also be noted that issues of social justice and equality are traditionally considered painful problems for our society. The idea of equality between people stems from the religious idea of equality of all before God and was established in the form of the perception of justice as a universally recognized equal necessary measure of behavior.

Many thinkers believe that true freedom lies within the boundaries of equality, is conditioned by equality, and it is in this capacity that it functions as a principle of law. As for equality itself, it consists of equality before necessity and equal fulfillment of what is necessary [Solovyov, 1910-1914]. Modern research distinguishes two types of equality: equality in content and equality in terms of social value. Human rights and freedoms are usually interpreted as the equality of identical rights and freedoms (for example, having an equal right to education or health care). However, in law enforcement practice, equality is more often encountered in terms of social significance rather than substantive content. This is enshrined in legal norms governing

civil contracts, employment contracts and many other legal relationships [Filimonov, 2009].

In terms of the recognition or denial of equality of opportunity among their members, societies are divided into paternalistic and egalitarian types, each exhibiting a diversity of moral values. Thus, in paternalistic societies the spirit of collectivism is high, while in egalitarian societies, on the contrary, individualism is more noticeable. In the Eastern world, where paternalism is widespread, the role of the political leader in power and the father in the family is extremely important, and they assume all the care for those under their protection. In the Western world, where egalitarianism is ingrained, individualism occupies a greater place, and the institution of subjective law as an emanation of individual will is widespread. In the East, the death sentence is passed by a judge (as if a government official), expressing the position of the state; in most Western countries, decisions on severe punishments are made by jurors representing public opinion.

In paternalistic states, the inadmissibility of phenomena that can be considered negative from a moral point of view is reflected in laws based on the general opinion of the collective, whereas in egalitarian societies one can see that a number of moral shortcomings are perceived as a common occurrence, and sometimes even enshrined in legislation. However, in a paternalistic society, the “superior” decides everything for the “inferior” individual in socio-political terms, which leads to the widespread spread of conformism and infantilism. As a result, a weakening of political and economic initiative and activity, the emergence of economic depressions and crises of power become inevitable. As for Azerbaijan, it is difficult to classify our country in its pure form as either an Eastern or a Western society. The moral and ideological foundations proclaimed and in force in Azerbaijan indicate that our society has its own unique development path.

Since the 20th century, Azerbaijani society has combined important features of both Eastern and Western civilizations, reflecting universal human values alongside Islamic values in its everyday life, thought, and legal system. Consequently, the characteristic traits of the country's citizens include a desire for economic and political activity, attempts to influence policy, and, in some cases, a procrastination and passive political and legal behavior, as well as a desire to build their own businesses or to have no one interfere in family matters. At the same time, they demonstrate in their thoughts and actions the need for a strong and caring hand to constantly be over them, the need for a head of state who embodies the personality of a father at the state level.

The category of justice, acting as another moral value, extends to all spheres of public and private relations, including legal and political relations, law and politics. Even ancient Greek thinkers believed that justice serves to soften the severity of the law. Justice, acting in relation to the law as an ideal, goal, principle, does not have a mechanism for implementing its "demands." Unlike justice, the law itself has the means of implementation. The great Azerbaijani thinker Nasiruddin Tusi said: "By its essence, justice expresses the desire for both objective reward and deserved punishment. There can be no one-sided approach here. Everything must occur in accordance with the logic of things. Honest and selfless work is the basis of justice ... It is necessary to strive to protect income, acquired wealth and to satisfy the needs of everyone in proportion to their contribution to the general abundance" [Khaja Nasiruddin Tusi, 2005]. In these thoughts of the thinker, we see a clear expression of the boundaries between justice and injustice. One cannot but agree with the following opinion of the modern researcher A.A. Huseinov: "Justice involves evaluating a person based on their actions, rewarding them for their merits, which requires at least two things: a standard (norm, model) for measuring actions and a person entrusted with this measurement. For this reason, justice is naturally identified with the rule of law and justice..." [Huseinov, 2008].

Being a value, justice is in many cases placed above law. In our consciousness, justice harmonizes with truth and fairness. Truth is not only the verity, but also an emotional state. In people's minds, law and justice have a value only when they reflect justice and truth. At the same time, it is necessary to distinguish between the fairness of law and the fairness of the application of law. Herbert Hart rightly noted that "the assertion that one of the essential elements of the concept of justice is the principle of deciding like cases alike is true. This is justice in the application of law, but not the justice of law. Thus, in the very concept of general norms as an essential feature of law, there is something that prevents us from considering it neutral from the point of view of, and without some necessary connection with, moral principles." Natural procedural justice thus consists of those principles of objectivity and impartiality in the application of law which implement only this aspect of law and which are created in order to ensure that the rules are applied only to cases corresponding to their content or, at least, to reduce the risk of inequality in this sense." [Hart, 1958].

No matter how "fair" the law and the rule of law may be, if their application is not based on objectivity and fairness, faith in justice is gradually lost. On the contrary, the fair application of even a less "fair" law leads to an increase in this faith and, ultimately, to the strengthening of moral and ethical values in the minds of people. In this regard, the loyalty of law enforcement officers, especially those working in the field of justice, the prosecutor's office, internal affairs, customs, taxation and other areas, to moral values has an indirect but important impact on the purification of society and the enhancement of the political and legal culture of its members.

The commitment of every civil servant to the rule of law, human rights, democratic principles, and high ethical standards of conduct is established by the Law of the Republic of Azerbaijan "On the Rules of Ethical Conduct of Civil Servants" dated May 31, 2007 [Law of the Republic of Azerbaijan, 2007]. Based on this law, the adopted codes and rules of ethical conduct for judges, lawyers, prosecutors, justice officials, employees of the internal affairs agencies, tax and customs authorities, and those working in other government agencies reflect the set of ethical principles and standards of activity in the relevant agencies. They regulate specific requirements of morality and decency, issues of professional ethics, and conduct outside of official duties, and

define their attitude toward professional activity [Collection of Codes of Ethical Conduct, 2016]. As noted in these regulations, those working in the aforementioned agencies must be guided in their activities by respect for human and civil rights and freedoms, legality, humanism, and other democratic principles, as well as high standards of ethical conduct. Proper performance of their legally imposed duties directly depends on high moral and professional qualities, dignity, respect in society, a culture of behavior in their free time, and, in general, on a commitment to generally accepted moral and ethical values.

It should also be noted that ethical codes even possess some advantages over legal codes. Because the legal code, by its very nature, requires a precise definition of the elements of prohibited acts, as well as the necessary rules of conduct. But here one peculiarity emerges, which is the impossibility of creating a complete list of prohibitions and regulations. The basis of a moral and ethical code is not, first of all, norms, but principles of law, which are easier to align with the actual practical activities of a particular official. On the other hand, the specific nature of certain administrative offenses, which are not entirely correct from a political perspective, is such that proving guilt is difficult, and without it, it is impossible to apply legal sanctions. It should also be noted that many actions, by their very nature, cannot be regulated by law, but are expressed through moral and ethical norms, and the impact of the latter is, in most cases, more effective than that of legal norms. This is because moral norms act as fundamental determinants of human social behavior. Law, however, regulates only a certain portion of human actions.

If morality expresses the maximum value completeness, then law contains the minimum and sufficient. In this regard, law (as well as politics) will always be consistent with moral values and, being consistent with them, will be evaluated through them. Moral values such as selflessness, kindness, honesty, freedom, necessity, responsibility, keeping promises, a sense of duty, morality, usefulness, fidelity, mercy, justice, equality, striving for perfection, and altruism express universal human values and have historically acted as factors determining the fundamental moral and ethical orientation of individuals in society. Therefore, morality, both as a system of norms and as a system of values, can be assessed as an important condition shaping the value foundations of law. Among the values listed above, there are those that constitute not only morality but also the axiological foundations of law, the state, and politics. Values such as justice, freedom, equality, and humanism, which have moral, political, and legal foundations, manifest themselves in the form of ideals, goals, norms, and principles. They represent unique forms of social and individual assimilation of values and underlie the unique fusion of moral values with social reality, resulting in the progress of the political and legal system.

Summarizing the above, we can come to the conclusion that moral, political and legal thinking are organically linked to each other, are interconnected and closely dependent on each other. Formed on the basis of legal thinking, political consciousness brings clarity to the moral interactions existing in society and the state. On the other hand, at any stage of historical development, the comprehensive embodiment of social reality in the morality of people is more clearly reflected in the relationship between the individual and the state. The habits, knowledge, everyday norms, customs acquired by members of society over the centuries, and the experience resulting from them, clearly demonstrate the state of the political and legal system of the state in the corresponding period.

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MATHEMATICAL SCIENCES

SOLUTION OF ONE MIXED PROBLEM FOR A PARABOLIC EQUATION WITH A DISCONTINUITY AT THREE POINTS

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Abstract
The presented work considers the process of heat transfer[10]. Thus, the coefficients of the equation have a discontinuty at the point $x = 0$ and this equation is used to find a solution to a mixed problem involving the heat transfer process[5]. The contour integral method was applied to solve theconsidering problem ([2],[3]).

Keywords: Bessel function,the contour integralmethod, mixed problem, spectral problem, eigenvalues, asymptotics

INTRODUCTION

A large number of mathematical problems of an applied nature are expressed and investigated with the help of the apparatus of partial differential equations. When constructing a mathematical description of real processes, models of second-order partial differential equations, characterized by discontinuous coefficients, often arise. The development of a mathematical model for heat distribution in environments with different heat transfer characteristics is also an extension of this approach and increases the significance of this type of problem from both practical and theoretical perspectives. The problem we are considering reflects this.

1.THE SOLUTİON OF ONE MİXED PROBLEM İN A CYLİNDRİCAL MEDİUM FOR AN EQUATİON WİTH DİSCONTİNUOUS COEFFİCİENTS.

The problem of finding a solution to the following equation is considered ([8],[10]):

$$\frac{\partial u^{(i)}}{\partial t} = \chi_i \left(\frac{\partial^2 u^{(i)}}{\partial x^2} + \frac{1}{x} \frac{\partial u^{(i)}}{\partial x} \right) + f^{(i)}(x,t), (i = \overline{1,3}) \tag{1}$$

which satisfies the following boundary condition:

$$u^{(1)}(0,t) = \mathrm{c}_0$$

$$\left. \frac{\partial u^{(i)}}{\partial x} \right|_{x=a_i} + h_i \{ u^{(i+1)}(a_i,t) - u^{(i)}(a_i,t) \} = 0, i = 1,2,$$

$$\left. \frac{\partial u^{(i)}}{\partial x} \right|_{x=a_i-1} + l_{i-1} \{ u^{(i)}(a_{i-1},t) - u^{(i-1)}(a_{i-1},t) \} = 0, i = 2,3 \tag{2}$$

$$u^{(3)}(c,t) = 0,$$

also satisfy the initial condition

$$u^{(i)}(x,0) = \phi^{(i)}(x)\,, x \in (a_{i-1}, b_{i-1})\,. \tag{3}$$

Here constant numbers $\chi_i\,, h_i\ (i = \overline{1,3}), l_i\ (i = \overline{2,3})$ are parameters,the intervals $(a_{i-1}, b_{i-1})\ (i = 1,2,3)$ have common boundary points and do not intersect:

$$0 = a_0 < b_0 = a = a_1 < b_1 = b = a_2 < b_2 = a_3 = c.$$

Thus, the domain under consideration is divided into 3 parts $(0,a), (a,b)$ and (b,c), and these intervals converge only at the ends.

The function $f^{(i)}(x,t)$ in the equation is chosen in the following form:

$$f^{(i)}(x,t) == \begin{cases} 0, at\ x \in (0,a), \\ Ax, at\ x \in (a,b), \\ 0, at\ x \in (b,c). \end{cases} \tag{4}$$

and the initial functions $\phi^{(i)}(x)\ (i = \overline{1,3})$ are given as follows:

$$\phi^{(i)}(x)=\begin{cases}\alpha\ ln\frac{a}{b}+\beta, i=1, at\ x\in(0,a),\\ \alpha\ ln\frac{x}{b}+\beta, i=2, at\ x\in(a,b),\\ \gamma\ ln\frac{x}{c}+\delta, i=3, at\ x\in(b,c),\end{cases} \tag{5}$$

where $\alpha,\beta,\gamma,\delta$ are constants.

2.CONSTRUCTİNG OF THE GREEN'S FUNCTİON , CORRESPONDİNG TO SPECTRAL PROBLEM AND DETERMİNATİON OF THE EİGENVALUES

Consider the problem:

$$x_i\left(\frac{d^2y^{(i)}}{dx^2}+\frac{1}{x}\frac{dy^{(i)}}{dx}\right)-\lambda^2y^{(i)}=\begin{cases}0, i=1\\ \varphi^i(x), i=2,3\end{cases} \tag{6}$$

$$y^{(1)}(0,\lambda)=\frac{c_0}{\lambda}<\infty$$

$$\left.\frac{dy^{(1)}}{dx}\right|_{x=a}+h_1\left(y^{(2)}(a,\lambda)-y^{(1)}(a,\lambda)\right)=\frac{V_1}{\lambda^2}$$

$$\left.\frac{dy^{(2)}}{dx}\right|_{x=a}+l_1\left(y^{(2)}(a,\lambda)-y^{(1)}(a,\lambda)\right)=\frac{V_2}{\lambda^2}$$

$$\left.\frac{dy^{(2)}}{dx}\right|_{x=b}+h_2\left(y^{(3)}(b,\lambda)-y^{(2)}(b,\lambda)\right)=\frac{V_3}{\lambda^2}$$

$$\left.\frac{dy^{(3)}}{dx}\right|_{x=b}+l_2\left(y^{(3)}(b,\lambda)-y^{(2)}(b,\lambda)\right)=\frac{V_4}{\lambda^2}$$

$$\left.\frac{dy^{(3)}}{dx}\right|_{x=c}-h_3y^{(3)}(c,\lambda)=0 \tag{7}$$

This problem is called the spectral problem corresponding to the mixed problem.

In this section, we investigate the spectral problem depending on the parameter. The goal is to establish both a general solution and determine the corresponding spectral values. For this, it is appropriate to divide the problem into two separate auxiliary problems. As the first problem, let us find a solution to the homogeneous differential equation (6) that satisfies the given boundary conditions. Let us denote this solution as $y_1^{(i)}(x,\lambda)$. The second problem consists in finding a solution to equation (6) that satisfies the corresponding homogeneous boundary conditions. Let us denote this solution by $y_2^{(i)}(x,\lambda)$. In this case, it is obvious that the solution to the problem is the sum of the solutions həlli $y_1^{(i)}(x,\lambda)$ and $y_2^{(i)}(x,\lambda)$:

$$y^{(i)}(x,\lambda)=y_1^{(i)}(x,\lambda)+y_2^{(i)}(x,\lambda) \tag{8}$$

Solution of the first problem at $x\in(a_{i-1},b_{i-1})$ has the form:

$$y_1^{(i)}(x,\lambda)=\frac{\Delta_1^{(i)}(x,\lambda)}{\Delta(\lambda)},(i=\overline{1,3}) \tag{9}$$

$$\frac{d^my_{11}^{(i)}}{dx^m}=\left(\frac{\lambda}{k_i}\right)^m\left\{\left(\frac{a_ik_i}{2x}\right)^{\frac{1}{2}}+\frac{\eta_{1m}^{(i)}(x)}{\lambda}+\frac{E_{1m}^{(i)}(x,\lambda)}{\lambda^2}\right\}e^{\frac{x-a_i}{k_i}\lambda}$$

$$\frac{d^my_{12}^{(i)}}{dx^n}=\left(-\frac{\lambda}{k_i}\right)^m\left\{\left(\frac{-a_ik_i}{2x}\right)^{\frac{1}{2}}+\frac{\eta_{1m}^{(i)}(x)}{\lambda}+\frac{E_{1m}^{(i)}(x,\lambda)}{\lambda^2}\right\}e^{\frac{-\lambda(x-a_i)}{k_i}} \tag{10}$$

Therefore, the analytically bounded functions funksiya $k_i=\sqrt{\chi_i}$, $i=2,3$, and $E_{jm}^{(i)}(x,\lambda)$ $(i=2,3;\ j=1,2;\ m=0,1,2)$ are functions with respect to the parameter λ in the expression, and these functions are also continuous on the intervals $x\in(a_{i-1},b_{i-1})$ $(i=2,3)$.

It is clear that the solution to the second problem is given by the Green's function ([2],[6]), where the solution is written as an integral expression:

$$y_2^{(i)}(x,\lambda)=\int_a^b G^{(i,2)}(x,\xi,\lambda)\varphi^{(2)}(\xi)d\xi++\int_b^c G^{(i,3)}(x,\xi,\lambda)\varphi^{(3)}(\xi)d\xi\ ,(i=\overline{1,3}) \tag{11}$$

where $G^{(i,j)}(x,\xi,\lambda)$ $(i=\overline{1,3};j=\overline{2,3})$ is a Green function and

$$G^{(i,j)}(x,\xi,\lambda)=\frac{\Delta^{(i,j)}(x,\xi,\lambda)}{x_j\Delta(\lambda)}\ (i=\overline{1,3};j=\overline{2,3}).$$

The asymptotics for $Re\lambda>0$ are defined in a similar way. Finally, the following asymptotic formula is obtained for the roots of the characteristic equation Δ(λ)=0 ([1],[4]).

$$\lambda_\nu=\frac{k_2k_3\nu\pi}{k_3(b-a)+k_2(c-b)}\left\{[1]+o\left(\frac{1}{\nu}\right)\right\},\nu=0,\pm1,\pm2. \tag{12}$$

Using the obtained asymptotics, we can write the expression shown for the determinant $\Delta(\lambda)$ in the remaining part of the , λ-plane, except for the δ - neighborhood of the spectra given in ([7],[3]):

$$\left|\lambda^{4+\frac{1}{2}}\cdot e^{-\lambda\frac{a}{k_1}}\Delta(\lambda)\right| > N_\delta \tag{13}$$

where N_δ is a constant that is positive and depends only on δ.

3. EVALUATION OF THE SOLUTION OF THE SPECTRAL PROBLEM

In order to find the functions $\Delta_1^{(i)}(x,\lambda)$ let us use the asymptotic expression of the Bessel function as well as the asymptotic expressions derived for the elements of the characteristic determinant [9]. As a result of this approach,we obtain in the cases where $i = 1,2,3$:

$$\begin{aligned}
\Delta_1^{(1)}(x,\lambda) &= \lambda^{3+\frac{1}{2}}\left\{A_1^{(1)}(x,\lambda)e^{\lambda\frac{x-a}{k_1}} + A_2^{(1)}(x,\lambda)e^{-\lambda\frac{x-a}{k_1}}\right\}e^{-\lambda\left(\frac{a}{k_1}+\frac{b-a}{k_2}+\frac{c-b}{k_3}\right)}\\
\Delta_1^{(2)}(x,\lambda) &= \lambda^{3+\frac{1}{2}}\left\{A_1^{(2)}(x,\lambda)e^{\lambda\frac{x-a}{k_2}} + A_2^{(2)}(x,\lambda)e^{-\lambda\frac{x-b}{k_2}}\right\}\\
\Delta_1^{(3)}(x,\lambda) &= \lambda^{3+\frac{1}{2}}\left\{A_1^{(3)}(x,\lambda)e^{\lambda\frac{x-b}{k_3}} + A_2^{(3)}(x,\lambda)e^{-\lambda\frac{x-c}{k_3}}\right\}e^{-\lambda\left(\frac{a}{k_1}+\frac{b-a}{k_2}+\frac{c-b}{k_3}\right)}
\end{aligned} \tag{14}$$

The first formula of these expressions is true in $x \in [\varepsilon, a)$, $\varepsilon > 0$, the second formula is true in $x \in [a,b]]$ and the third is true in the interval $x \in [b,c]$. It can be concluded that for, $i = 1$ at $x \in [\varepsilon, a]$; for $i = 2,3$ at $x \in (a_{i-1};\ b_{i-1})$ (i-1); b_(i-1)) the following estimate is true for the solution of the first problem and its derivatives with respect to x up to the m-th order, under the condition $\lambda \in T_\nu$ [2]:

$$\left|\frac{1}{\lambda}\frac{d^m}{dx^m}y_1^{(i)}(x,\lambda)\right| \le \frac{M_1 e^{\alpha_i\lambda} + M_2 e^{\beta_i\lambda}}{|\lambda|^{2-m}} \tag{15}$$

The parameters for $i = 1,2,3;\ m = 0,1,2$ are defined as follows:,

$$\begin{aligned}
\alpha_1 &= \frac{x+a}{k_1};\ \beta_1 = \frac{a-x}{k_1}, x \in [\varepsilon; a]\\
\alpha_2 &= \frac{x-a}{k_2};\ \beta_2 = \frac{b-x}{k_2}, x \in [a; b]\\
\alpha_3 &= \frac{x-b}{k_3};\ \beta_3 = \frac{c-x}{k_3}, x \in [b; c]
\end{aligned}$$

The domain T_ν consists of the corresponding arcs of circles with radius r_ν, centered at the origin in the complex plane.

By applying the same method, the appropriate asymptotic behavior is determined for the solution of problem II. When $\mathrm{Re}\,\lambda < 0$, the function $y_2^{(i)}(x,\lambda)$ and its derivatives have a similar type of exponential-decreasing and power-like evaluation.

$$\begin{aligned}
\frac{d^m y_2^{(1)}(x,\lambda)}{dx^m} &= \lambda^{m-2}\left\{\left(\sum_{n=1}^{4}\mathcal{D}_{n_{11}}^{(m)}(x,\lambda)e^{\lambda\frac{x+a}{k_1}} + C_{n+1}^{(m)}(x,\lambda)e^{\lambda\frac{a-x}{k_1}}\right)\cdot\int_a^b\left[\sqrt{\xi}\right]\omega_{n_2}\varphi^{(2)}(\xi)d\xi\right.\\
&\left.+\left(\sum_{n=1}^{3}\mathcal{D}_{n+2}^{(m)}(x,\lambda)e^{\lambda\frac{x+a}{k_1}} + C_{n+2}^{(m)}(x,\lambda)e^{\lambda\frac{a-x}{k_1}}\right)\cdot\int_a^b\left[\sqrt{\xi}\right]\omega_{n_3}\varphi^{(3)}(\xi)d\xi\right\}, at\ x \in [\varepsilon, a]\\
\frac{d^m y_2^{(2)}(x,\lambda)}{dx^m} &= \lambda^{m-1}\left\{\left(\sum\nolimits_{n=1}^{4}\mathcal{D}_{n_{21}}^{(m)}(x,\lambda)e^{\lambda\frac{x-c}{k_2}} + +C_{n_{21}}^{(m)}(x,\lambda)e^{\lambda\frac{b-x}{k_1}}\right)\int_a^b\left[\sqrt{\xi}\right]\omega_{n_2}\varphi^{(2)}(\xi)d\xi +\right.\\
&\left(\sum\nolimits_{n=1}^{3}\mathcal{D}_{n_{22}}^{(m)}(x,\lambda)e^{\lambda\frac{x-c}{k_2}} + +C_{n_{22}}^{(m)}(x,\lambda)e^{\lambda\frac{b-x}{k_2}}\right)\cdot\int_b^c\left[\sqrt{\xi}\right]\omega_{n_3}\varphi^{(3)}(\xi) - \frac{\varepsilon m_2}{x_2}\int_a^x\left(\frac{k_2}{2}\sqrt{\frac{\xi}{x}} +\right.\\
&\left.\left.+\frac{1}{\lambda}\left[\eta_{m_1}^{(2)}(x,\xi)\right]\right)e^{\lambda\frac{x-\xi}{k_2}}\varphi^{(2)}(\xi)d\xi + (-1)^m\frac{\varepsilon m_2}{k_2}\int_x^b\left(-\frac{k_2}{2}\sqrt{\frac{\xi}{x}} + +\frac{1}{\lambda}\left[\eta_{m_2}^{(2)}(x,\xi)\right]\right)e^{-\lambda\frac{x-\xi}{k_2}}\varphi^{(2)}(\xi)d\xi\right\}, at\ x \in [a,b]\\
\frac{d^m y_2^{(3)}(x,\lambda)}{dx^m} &= \lambda^{m-1}\left\{\left(\sum\nolimits_{n=1}^{4}\mathcal{D}_{n_{31}}^{(m)}(x,\lambda)e^{\lambda\frac{x-b}{k_3}} + +C_{n_{31}}^{(m)}(x,\lambda)e^{\lambda\frac{c-x}{k_1}}\right)\int_a^b\left[\sqrt{\xi}\right]\omega_{n_2}\varphi^{(2)}(\xi)d\xi +\right.\\
&\left(\sum\nolimits_{n=1}^{3}\mathcal{D}_{n_{32}}^{(m)}(x,\lambda)e^{\lambda\frac{x-b}{k_3}} + +C_{n_{32}}^{(m)}(x,\lambda)e^{\lambda\frac{c-x}{k_3}}\right)\cdot\int_b^c\left[\sqrt{\xi}\right]\omega_{n_3}\varphi^{(3)}(\xi) - \frac{\varepsilon m_3}{x_3}\int_b^x\left(\frac{k_3}{2}\sqrt{\frac{\xi}{x}} +\right.\\
&\left.\left.+\frac{1}{\lambda}\left[\eta_{m_1}^{(3)}(x,\xi)\right]\right)e^{\lambda\frac{x-\xi}{k_3}}\varphi^{(3)}(\xi)d\xi + (-1)^m\frac{\varepsilon m_3}{k_3}\int_x^c\left(-\frac{k_3}{2}\sqrt{\frac{\xi}{x}} + +\frac{1}{\lambda}\left[\eta_{m_2}^{(3)}(x,\xi)\right]\right)e^{-\lambda\frac{x-\xi}{k_3}}\varphi^{(3)}(\xi)d\xi\right\}, x \in [b,c]\\
&m = (0,1,2)
\end{aligned} \tag{16}$$

Note that the functions , $\mathcal{D}_{mj}^{(m)}(x,\lambda)$ and $C_{mj}^{(m)}(x,\lambda)$ are bounded on the contours of $\mathcal{T}_\nu$ in the following cases: in the case of $i = 1$ at $x \in [\varepsilon; a]$, and in addition, in the case of $i = 2,3$ at $x \in [a_{i-1}; b_{i-1}]$, where at $i = 1,2,3$ and $j = 1,2$ i=1,2,3 this is true.

As was emphasized, it is not immediately obvious that the solution of the spectral problem considered in the interval $x \in (0;\ a)$ is bounded on this boundary, since the coefficient of the equation is discontinuous at the point $x = 0$. Therefore, the solution in this interval was found and investigated only for values $x \in [\varepsilon; a]$ $(\varepsilon > 0)$.

In this section, we present an estimate of the function $y_1^{(1)}(x,\lambda)$ for the solution of the corresponding spectral problem in the interval $x \in (0, a)$:

$$\left|y_1^{(1)}(x,\lambda)\right| \le \begin{cases} c_{15}|\lambda|^{-\frac{1}{2}} e^{-\left(\frac{x}{k_1}+\beta\right)Re\,\lambda}; \frac{\pi}{2} < \arg\lambda < \frac{3\pi}{2}, \\ c_{25}|\lambda|^{-\frac{1}{2}} e^{\left(\frac{x}{k_1}+\beta\right)Re\,\lambda};\ -\frac{\pi}{2} < \arg\lambda < \frac{\pi}{2}. \end{cases} \tag{17}$$

Then let's consider the second problem. Let's evaluate the solution $y_2^{(1)}(x,\lambda)$ of the given problem. In the entire domain of the complex λ--plane, we finally obtain this inequality for the solution corresponding to the case $i = 1$ of the problem:

$$\left|y_2^{(1)}(x,\lambda)\right| \le \begin{cases} \frac{2BA}{|\lambda|^2} e^{-\left(\frac{x}{k_1}+\beta\right)Re\lambda}; \frac{\pi}{2} < \arg\lambda < \frac{3\pi}{2}, \\ \frac{2BA}{|\lambda|^2} e^{\left(\frac{x}{k_1}+\beta\right)Re\lambda};\ -\frac{\pi}{2} < \arg\lambda < \frac{\pi}{2}. \end{cases} \tag{18}$$

4. SOLUTION OF THE MIXED PROBLEM

In this section, an analytical representation of the solution of the given mixed-type problem in the form of a contour integral is given and it is justified that this expression satisfies both the boundary and initial conditions ([2],[3],[7]). Thus, for $x \in (a_{i-1}, b_{i-1})$ $(i = \overline{1,3})$ and $t > 0$, let us consider the equation

$$\frac{\partial p^{(i)}}{\partial t} = x_i\left(\frac{\partial^2 p^{(i)}}{\partial x^2} + \frac{1}{x}\frac{\partial p^{(i)}}{\partial x}\right). \tag{19}$$

In this problem, the boundary conditions for $t > 0$ are as follows:

$$\begin{gathered} p^{(1)}(0,t) = c_0 < \infty \\ \left.\frac{\partial p^{(1)}}{\partial x}\right|_{x=a} + h_1\left(p^{(2)}(a,t) - p^{(1)}(a,t)\right) = V_1 \\ \left.\frac{\partial p^{(2)}}{\partial x}\right|_{x=a} + l_1\left(p^{(2)}(a,t) - p^{(1)}(a,t)\right) = V_2 \\ \left.\frac{\partial p^{(2)}}{\partial x}\right|_{x=b} + h_2\left(p^{(3)}(b,t) - p^{(2)}(b,t)\right) = V_3 \\ \left.\frac{\partial p^{(3)}}{\partial x}\right|_{x=b} + l_2\left(p^{(3)}(b,t) - p^{(2)}(b,t)\right) = V_4 \\ \left.\frac{\partial p^{(3)}}{\partial x}\right|_{x=b} - h_3 p^{(3)}(c,t) = 0 \end{gathered} \tag{20}$$

On the other hand at $x \in (a_{i-1}, b_{i-1})$ initial condition has the form:

$p^{(1)}(x,0) = 0,\ p^{(2)}(x,0) = \varphi^2(x),\ p^{(3)}(x,0) = \varphi^{(3)}$ (2.48)

Let's consider the following theorems:

Theorem 1. (Equation (19) has a unique solution that satisfies the boundary conditions and zero initial conditions, and this solution is given by the following formula:

$$p_1^{(i)}(x,t) = \frac{1}{\sqrt{\pi - i}}\int_S \frac{y_1^{(i)}(x,\lambda)}{\lambda} e^{\lambda^2 t}\, dt \tag{21}$$

where $y_1^{(i)}(x,\lambda)$ is the solution to the I spectral problem and $t > 0$, $x \in (a_{i-1}, b_{i-1})$, $i = 1,2,3$.

Theorem 2. Equation (19) has a unique solution satisfying homogeneous boundary conditions and initial conditions, and it has the following analytical expression:

$$p_2^{(i)}(x,t) = \frac{1}{\pi\sqrt{-1}}\int_S \lambda y_2^{(i)}(x,\lambda) e^{\lambda^2 t}\, d\lambda, \tag{22}$$

where $y_2^{(i)}(x,\lambda)$ is the solution to the II spectral problem, corresponding to (4.1)-(4.3).

Let S denote an infinitely extendable contour lying entirely in the domain $R_\delta = \left\{\lambda: |\lambda| > R\ |\arg\lambda| < \frac{\pi}{4} + \delta\right\}$ and whose infinitely distant parts coincide with the rays $\arg\lambda = \pm\left(\frac{\pi}{4} + \delta\right)$.

Consequently, the sum of these two solutions constitutes the general solution of the mixed problem. That is, the function

$$p^{(i)}(x,t) = p_1(x,t) + p_2(x,t) \tag{23}$$

is the required solution of the given mixed problem.

In this case, it is true that the function $p^{(i)}(x,t)$ also satisfies the first of the boundary conditions.

İn other words, for $i = 1$ the equality

$$p^{(1)}(0,t) = c_0 < \infty$$

must bu proven to be true. To do this, it is necessary to prove that the integrals mentioned below converge regularly for all $\lambda \in R_\delta$ in case of $x \in [0,a]$ and $t \in [0,T]$.

$$\int_S \frac{1}{\lambda} y_1^{(1)}(x,\lambda) e^{\lambda^2 t} d\lambda \text{ və } \int_S \lambda y_2^{(1)}(x,\lambda) e^{\lambda^2 t} d\lambda \tag{24}$$

Let us denote the intersection points of the contour S of the circles with radii r_n and $r_{n+\nu}$ and centered at the origin in the λ -complex plane as a_n, $a_{n+\nu}$; a'_n and $a'_{n+\nu}$, respectively.

In this case, to show that the given integrals

$$\int\limits_{\overline{a_n a_{n+\nu}}} \frac{1}{\lambda} y_1^{(1)}(x,\lambda) e^{\lambda^2 t} d\lambda ; \int\limits_{\overline{a'_n a'_{n+\nu}}} \frac{1}{\lambda} y_1^{(1)}(x,\lambda) e^{\lambda^2 t} d\lambda$$
$$\int\limits_{\overline{a_n a_{n+\nu}}} \lambda y_2^{(1)}(x,\lambda) e^{\lambda^2 t} d\lambda \int\limits_{\overline{a'_n a'_{n+\nu}}} \lambda y_2^{(1)}(x,\lambda) e^{\lambda^2 t} d\lambda \tag{25}$$

regularly converge it is sufficient to show that the integrals are sufficiently small when $|\lambda|$ takes sufficiently large values.

According to (16), we can write the following inequality:

$$\left| \int\limits_{\overline{a_n a_{n+\nu}}} \frac{1}{\lambda} y_1^{(1)}(x,\lambda) e^{\lambda^2 t} d\lambda \right| \le \int\limits_{\overline{a_n a_{n+\nu}}} \frac{1}{|\lambda|} \left| y_1^{(1)}(x,\lambda) \right| \left| e^{\lambda^2 t} \right| |d\lambda| \le\le c_1 \int\limits_{\overline{a_n a_{n+\nu}}} \frac{1}{|\lambda|^{\frac{3}{2}}} e^{\left(\frac{x}{k_1}+\beta\right) Re\lambda} e^{Re\lambda^2 t} |d\lambda|$$
$$= c_1 \int\limits_{\overline{a_n a_{n+\nu}}} e^{\left(\frac{x}{k_1}+\beta\right) Re\lambda + Re\lambda^2 t} |d\lambda| \tag{26}$$

If $\lambda \in a_n a_{n+\nu}$, then

$$\left| e^{\lambda^2 t} \right| = e^{Re\lambda^2 t} = e^{|\lambda|^2 t \cos^2 \arg\lambda} = e^{|\lambda|^2 + (2\cos^2 \arg\lambda - 1)} = e^{-|\lambda|^2 t (1-2\delta^2)} .$$

Therefore, it is true that $\arg\lambda = \frac{\pi}{4} + \delta$ and $2\cos^2 \arg\lambda - 1 = -\varepsilon$ are true on this contour. We can then write:

$$\left| \int\limits_{\overline{a_n a_{n+\nu}}} \frac{y_1^{(1)}}{\lambda} d\lambda \right| < c_1 \int\limits_{\overline{a_n a_{n+\nu}}} \frac{\left(\frac{x}{k_1}+\beta\right) |\lambda| \cos\arg\lambda - |\lambda|^2 t}{|\lambda|^{\frac{3}{2}}} |d\lambda| =$$
$$= c_1 \int_{\overline{a_n a_{n+\nu}}} e^{\left(\frac{x}{k_1}+\beta\right)|\lambda|\delta - (1-2\delta^2)|\lambda|^2 t} \frac{d\lambda}{|\lambda|^{\frac{3}{2}}} \le c_1 \int_{r_n}^{r_{n+\nu}} e^{-r\left((1-2\delta^2)2t - \left(\frac{x}{k_1}+\beta\right)\delta\right)} dr <$$
$$c_1 \int_{r_n}^{\infty} e^{-r\left((1-2\delta^2)rt - \left(\frac{x}{k_1}+\beta\right)\delta\right)} \frac{dr}{r^{\frac{3}{2}}} .$$

It is clear from this that if we take the expression $|\lambda| = r$ large enough for all $x \in [0,a]$, the following equality is satisfied:

$(1-2\delta^2)rt - \left(\frac{x}{k_1}+\beta\right)\delta > 0.$

From this we can say that the value of the integral

$$\int\limits_{\overline{a_n a_{n+\nu}}} \frac{y_1^{(1)}(x,\lambda)}{\lambda} d\lambda$$

becomes sufficiently small for sufficiently large |λ|

The same analytical approach can be applied to other integrals. As a result, we can easily obtain the limit at $x \to 0$ in the first expression, and thus:

$$u_1^{(1)}(0,t) = \lim_{x\to 0} u_1^{(1)}(x,t) = \lim_{x\to 0} \frac{1}{\pi\sqrt{-1}} \int_S \frac{y_1^{(1)}(x,\lambda) e^{\lambda^2 t}}{\lambda} d\lambda = \frac{1}{\pi\sqrt{-1}} \int_S \frac{e^{\lambda^2 t}}{\lambda} \lim_{x\to 0} y_1^{(1)}(x,\lambda)\, d\lambda$$
$$= \frac{c_0}{\pi\sqrt{-1}} \int_S \frac{e^{\lambda^2 t}}{\lambda} d\lambda == \frac{c_0}{\pi\sqrt{-1}} \lim_{n\to\infty} \int_{S_n} \frac{e^{\lambda^2 t}}{\lambda} d\lambda = \frac{c_0}{2\pi\sqrt{-1}} \lim_{n\to\infty} \oint_{\Gamma_n} \frac{e^{\lambda^2 t}}{\lambda} d\lambda =$$
$$= \frac{c_0}{2\pi\sqrt{-1}} 2\pi\sqrt{-1} \frac{e^{\lambda^2 t}}{1}\Big|_{\lambda=0} = c_0 .$$

As a result, it is proven that the function $u_1^{(1)}(x,t)$), i.e. $u_1^{(1)}(0,t) = c_0$ completely satisfies the first boundary condition. By a similar argument, it can be shown that

$$\lim_{n\to\infty} \int\limits_{\overline{a_n a_{n+\nu}}} \lambda y_2^{(1)}(x,\lambda) d\lambda = \lim_{n\to\infty} \int\limits_{\overline{a'_n a'_{n+\nu}}} \lambda y_2^{(1)}(x,\lambda) d\lambda = 0 .$$

Therefore,

$$u_2^{(1)}(0,t) = \lim_{x\to 0} u_2^{(1)}(x,t) = \lim_{x\to 0} \frac{1}{\pi\sqrt{-1}} \int_S \lambda y_2^{(1)}(x,\lambda) e^{\lambda^2 t} d\lambda =$$
$$= \frac{1}{\pi\sqrt{-1}} \int_S \lambda e^{\lambda^2 t} y_2^{(1)}(x,\lambda) d\lambda = \frac{c_0}{\pi\sqrt{-1}} \int_S \lambda e^{\lambda^2 t} d\lambda = 0 .$$

The function involved in the integral is analytic and therefore its derivative is zero.

As a result, the function given in (23) satisfies all the boundary conditions in (20), including the initial condition at $x = 0$.

CONCLUSION

This paper examines a mixed problem for a parabolic differential equation with variable coefficients. The fundamental properties of the characteristic determinant of the corresponding spectral problem are analyzed, and the necessary estimates for the Green's function are substantiated. As a result, a solution to the mixed problem under consideration is found in the form of a contour integral in the class of piecewise continuous functions.

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EXTENSION OF THE TOROIDAL TRANSPORT MODEL TO THE VON KÁRMÁN VORTEX STREET

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Abstract

In this paper, we formulate a reduced mathematical description of passive-scalar transport in a von Kármán vortex street by extending a local toroidal advection–filamentation model from an isolated coherent vortex to a spatially ordered chain of alternately signed vortices. The starting point is the observation that the vortex street is not itself a single invariant torus: the wake is time-dependent, vortices are shed, convected and deformed, and scalar material is repeatedly captured and released. Nevertheless, in a frame moving with an individual vortex, the scalar dynamics contains a near-integrable core with almost closed streamlines, surrounded by a strongly strained separatrix layer. This structure permits a multiscale description in which each coherent vortex carries a local action–angle dynamics, while weak non-integrable perturbations describe leakage, separatrix splitting and inter-vortex exchange. The resulting model combines three levels: local differential rotation and filamentation within a vortex, pairwise exchange between neighbouring vortices, and global transport along the wake. We derive the governing passive-scalar equations, introduce a Lamb–Oseen representation of the vortex street, formulate the local toroidal coordinates, obtain scaling laws for gradient growth and transverse filament thickness, and propose reduced amplitude equations for the evolution of scalar filaments. The theory is intended as a kinematic, analytically transparent analogue of a full Navier–Stokes simulation, and is particularly useful for interpreting Lagrangian computations of passive-scalar stretching in coherent vortex wakes.

Keywords: vortex street; passive scalar; chaotic advection; FTLE; Lagrangian coherent structures; filamentation; Hamiltonian dynamics; vortex tubes; mixing

1. Historical Background.

The study of the von Kármán vortex street dates back to the classical work of Theodore von Kármán [1], in which the regular pattern of alternating vortex shedding behind a bluff body was first established. It was shown that such a configuration represents a stable structure for flows at finite Reynolds numbers. In the following decades, the development of vortex theory, systematized in the monograph by Philip G. Saffman [2], provided a comprehensive framework for describing the dynamics of coherent vortex structures and their role in wake formation.

In parallel, it became clear that the transport of passive tracers in such flows is governed not only by turbulent effects, but also by the geometry of Lagrangian trajectories. The works of Hassan Aref [3] laid the foundation of the theory of chaotic advection, demonstrating that even deterministic laminar flows can produce exponential stretching of material lines. These ideas were further developed in the book by Julio M. Ottino [4], where a kinematic theory of mixing based on stretching and folding mechanisms was formulated.

With the development of Lagrangian methods for flow analysis, the concept of Lagrangian coherent structures (LCS) emerged as a central tool, formalized in the works of George Haller [5-6]. These studies showed that finite-time Lyapunov exponent (FTLE) fields reveal geometric structures that act as dynamical transport barriers. The theoretical framework and numerical methods for identifying such structures were further developed, in particular, by Shadden and co-authors [7].

At the same time, the theory of passive scalar transport relies on the classical results of George K. Batchelor [8], who showed that under strong shear conditions, scalar fields develop into thin filaments with concentration gradients amplified down to scales at which diffusion becomes dominant. This mechanism underlies the filamentation observed in vortex-dominated structures.

From a mathematical perspective, Lagrangian dynamics in two-dimensional incompressible flows is naturally formulated in Hamiltonian form, as rigorously established within the framework of classical mechanics by V.I.Arnold [9]. The development of the theory of perturbed integrable systems and the transition to chaos, presented in the works of Allan J. Lichtenberg and Michael A. Lieberman [10], provided a framework for describing the destruction of invariant tori and the emergence of chaotic advection in weakly non-integrable systems.

Against this background, the recent work of E. Milyute and A. Milyus [11] proposed a model of passive-scalar transport on toroidal stream surfaces, in which filamentation is driven by differential advection in an integrable vortex field. However, the application of this model to real flows, such as the von Kármán vortex street, requires accounting for unsteadiness and interactions between vortex structures.

The present work develops this idea and extends the toroidal model to the case of the von Kármán vortex street, interpreting it as a system of weakly perturbed local toroidal regions. Within each region, quasi-inte-

grable dynamics is preserved, while interactions between vortices lead to the breakdown of invariant structures and the emergence of chaotic transport.

2. Introduction. The transport of a passive scalar in coherent vortical flows is one of the classical problems of fluid mechanics. A passive scalar may represent dye, temperature in the absence of buoyancy feedback, salinity in a kinematic approximation, pollutant concentration, smoke, plankton density, or any material marker whose evolution is dominated by advection. Even when the scalar does not affect the velocity field, its distribution can develop very fine spatial scales. These scales are produced not by molecular diffusion alone but by the geometry of the velocity field: stretching, folding, differential rotation, separatrix crossing and repeated capture by coherent structures.

The purpose of this article is to construct a mathematical model for such scalar transport in a von Kármán vortex street. The model is based on a toroidal picture of transport in which scalar material is first considered inside a single coherent vortex as if it were moving on a family of closed or nearly closed stream surfaces. In an ideal toroidal model, the scalar is stretched by differential angular advection: particles at different radii rotate with different angular velocities, so that an initially localized patch is transformed into a long, thin filament. In a real vortex street the situation is more complicated. There is no single stationary torus filling the wake. Instead, vortices of alternating sign are shed behind an obstacle, convected downstream, and subjected to the strain of the mean flow and of neighbouring vortices. The scalar is therefore not permanently confined to one invariant surface. It is captured by a vortex, wound into spirals, expelled through a deformed separatrix, and then possibly captured again by another vortex.

The central claim of this paper is that the toroidal model remains useful if it is interpreted locally and asymptotically. It is not a global model of the entire vortex street. Rather, it is a local model of transport inside one coherent vortex element, supplemented by weak perturbation terms representing interaction with the rest of the street. This interpretation leads naturally to a hierarchy of reduced equations. At the first level, an isolated vortex is approximated by an integrable action–angle system. At the second level, neighbouring vortices and the background wake introduce slow radial drift, separatrix deformation and chaotic advection. At the third level, the full vortex street becomes a chain of capture–stretch–escape events

The article is written in the style of a reduced hydrodynamic theory. The aim is not to solve the Navier–Stokes equations directly, but to derive a coherent transport model from a prescribed, time-dependent velocity field. This approach is analogous in spirit to long-wave and defect theories in shear flows: one keeps the essential geometric mechanisms while replacing the full system by equations that are easier to analyse. Here the essential mechanism is not the instability of the velocity field itself, but the stretching and redistribution of scalar material in a vortex street.

3. Governing passive-scalar problem. Let (x, y) denote the streamwise and cross-stream coordinates in the wake of a circular cylinder or a compact bluff body. The incompressible velocity field is written as

$$\mathbf{u}(x, y, z) = \left(u_x, u_y\right), \nabla \cdot \mathbf{u} = 0 \quad (1)$$

The passive scalar is denoted by $\chi(x, y, t)$. In the purely advective limit it satisfies:

$$(\partial\chi/\partial t) + \mathbf{u} \cdot \nabla\chi = 0 \quad (2)$$

If molecular diffusion is retained, the equation becomes:

$$(\partial\chi/t) + \mathbf{u} \cdot \nabla\chi = \kappa\Delta\chi\,, \quad (3)$$

where κ is the scalar diffusivity. In Lagrangian form, particle trajectories obey

$$dX/dt = u_x(X, Y, t), dY/dt = u_y(X, Y, t) \quad (4)$$

and the scalar value carried by a particle is conserved when $\kappa = 0$:

$$D\chi/Dt = 0\,. \quad (5)$$

The dimensionless control parameter measuring the relative importance of advection and diffusion is the Péclet number:

$$Pe = U_\infty D/\kappa\,, \quad (6)$$

where U_∞ is the incoming velocity and D is a characteristic obstacle diameter. In the large-Péclet regime, scalar gradients may become very large before diffusion becomes important. This is the regime in which filamentation is most visible.

Because the velocity field is incompressible, one may introduce a streamfunction ψ, such that

$$u_x = \partial\psi/\partial y\,, u_y = -\partial\psi/\partial x\,. \quad (7)$$

The passive scalar equation can then be written as:

$$\chi_t + \mathcal{J}(\psi, \chi) = \kappa\Delta\chi\,, \quad (8)$$

where $\mathcal{J}(f, g) = f_x g_y - f_y g_x$ is the Jacobian. This form emphasizes the Hamiltonian character of two-dimensional incompressible advection: in the absence of diffusion, particles move along trajectories generated by a time-dependent Hamiltonian $\psi(x, y, t)$.

4. Kinematic representation of the vortex street. A von Kármán street may be represented kinematically as a mean stream plus a sequence of localized vortices. We write:

$$\mathbf{u}(x, y, t) = U_\infty \mathbf{e}_x + \sum_{n\in\mathbb{Z}} \boldsymbol{u_n}(x, y, t) + \mathbf{u}_b(x, y, t) \quad (9)$$

where $\mathbf{u}_b$ denotes the local correction due to the obstacle or near-wake region, and $\mathbf{u}_n$ is the velocity induced by the n-th vortex. A convenient smooth model is based on Lamb–Oseen vortices. The vorticity of the n-th vortex is approximated by

$$\omega_n(x, y, t) = (\Gamma_n/2\pi r_c^2)\exp[-h/2r_c^2] \quad (10)$$

where Γ_n is its circulation, r_c is the core radius, and $\left(X_n(t), Y_n(t)\right)$ is the vortex centre, $h = \left(x - X_n(t)\right)^2 + \left(y - Y_n(t)\right)^2$ (where **level sets** $h = const$ are *circles* centered at the vortex).

The total vorticity is then

$$\omega(x, y, t) \simeq \sum_{n\in\mathbb{Z}} \Gamma_n G\left(x - X_n(t), y - Y_n(t)\right)\,, \quad (11)$$

where the kernel has a Gaussian form:

$$G(\xi, \eta) = (1/2\pi r_c^2)\exp[-(\xi^2 + \eta^2)/2rc_c^2]. \quad (12)$$

This representation allows the vortex street to be described as a superposition of smoothed localized vortices, which is convenient for the subsequent analysis of passive scalar transport. The induced tangential velocity of one Lamb–Oseen vortex is:

$$u_\theta(r) = (\Gamma_n/2\pi r)(1 - \exp[-r^2/2r_c^2]) \quad (13)$$

so that in Cartesian form

$$u_n(x, y, t) = u_\theta(r_n)\begin{pmatrix} -b/r_n \\ a/r_n \end{pmatrix}, \quad (14)$$

where $a = x - X_n(t), b = y - Y_n\ (t)$ and the distance to the vortex center is given by: $r_n = \sqrt{a^2 + b^2}$.

This expression describes the rotational velocity field around the vortex center, taking into account the smoothed (Gaussian) core.

The staggered street is represented by two rows of vortices,:

$$X_n^+(t) = nL + U_c t, Y_n^+ = m, \Gamma_n^+ = \Gamma_0 \ , (15)$$

and

$$X_n^-(t) = nL + (L/2) + U_c t, Y_n^- = -m, \Gamma_n^- = -\Gamma_0 (16)$$

Here L s the streamwise spacing between vortices of the same sign, $2m$ is the cross-stream spacing between the two rows, and U_c is the convection velocity of the vortex street. This representation is not a full solution of the Navier–Stokes equations, but it captures the geometrical features relevant for scalar transport: rotating cores, strain layers between vortices, and downstream drift.

A passive scalar initially localized near the wake may be specified as a Gaussian packet:

$$\chi(x, y, 0) = \exp[-((x - x_0)^2 + (y - y_0)^2)/2\sigma_0^2] \quad (17)$$

In a Lagrangian computation, the initial distribution is discretized into an ensemble of particles $\big(x_i(t), y_i(t)\big)$, each carrying a scalar weight χ_i. The Eulerian field is subsequently reconstructed using a smoothing kernel W:

$$\chi(x, y, t) \simeq \sum_i \chi_i W\big(x - x_i(t), y - y_i(t)\big) \ (18)$$

This formula is also useful theoretically, because it makes clear that the apparent creation of scalar structure is a consequence of the deformation of the particle cloud.

5. Local co-moving coordinates near one vortex. Choose one vortex centre $\big(X_n(t), Y_n(t)\big)$. In the frame moving with that vortex we define:

$$\tilde{x} = x - X_n(t), \tilde{y} = y - Y_n(t) \ . \quad (19)$$

The local polar coordinates are:

$$\rho = \sqrt{\tilde{x}^2 + \tilde{y}^2}, \phi = \tan^{-1}(\tilde{y}/\tilde{x}) \ . \quad (20)$$

In these variables the Lagrangian equations can be written schematically as

$$\dot{\rho} = V_n(\rho, \phi, t), \dot{\phi} = \Omega_n(\rho, t) + W_n(\rho, \phi, t) \ , (21)$$

where Ω_n is the angular velocity generated by the vortex itself, while V_n and W_n contain non-axisymmetric effects, neighbouring vortices, mean shear, finite-core deformation and acceleration of the moving frame. For a Lamb–Oseen vortex,

$$\Omega_n(\rho) = u_\theta(\rho)/\rho = (\Gamma_n/2\pi\rho^2)(1 - \exp[-\rho^2/2r_c^2]). \ (22)$$

The ideal isolated-vortex limit is obtained by setting $V_n = 0, W_n = 0$. Then

$$\dot{\rho} = 0, \dot{\phi} = \Omega_n(\rho) \quad (23)$$

and each circle $\rho = const$ is an invariant curve. This is the two-dimensional analogue of an invariant toroidal surface. The scalar is not mixed across ρ, but it is sheared along ϕ. If two particles have radii ρ and $\rho + \Delta\rho$, their angular separation after time t changes by:

$$\Delta\phi \ \simeq \ \Delta\phi(0) + \Omega_n'(\rho)\Delta\rho t. \quad (24)$$

Thus an initially compact scalar patch is elongated into a spiral filament. This is the elementary toroidal mechanism: differential angular velocity converts radial thickness into azimuthal length. The passive scalar equation in local polar variables is:

$$\chi_t + V_n\chi_\rho + (\Omega_n + W_n)\chi_\phi = \kappa\big(\chi_{\rho\rho} + (1/\rho)\chi_\rho + (1/\rho^2)\chi_{\phi\phi}\big) \ . \quad (25)$$

In the isolated inviscid limit this reduces to

$$\chi_t + \Omega_n(\rho)\chi_\phi = 0 \ , \quad (26)$$

whose exact solution is:

$$\chi(\rho, \phi, t) = \chi_0(\rho, \phi - \Omega_n(\rho)t) \ . \quad (27)$$

From this expression one directly obtains the growth of gradients. Differentiating with respect to ρ :

$$\chi_\rho(\rho, \phi, t) = \chi_{0\rho}(\rho, \phi - \Omega t) - t\Omega_n'(\rho)\chi_{0\phi}(\rho, \phi - \Omega t) (28)$$

so that for large time, provided $\Omega_n'(\rho) \neq 0$,

$$|\nabla\chi| \sim t|\Omega_n'(\rho)|\big|\chi_{0\phi}\big|. \quad (29)$$

The transverse filament thickness therefore scales as

$$\ell_\perp(t) \sim \ \ell_0/(1 + |\Omega_n'(\rho)|t) \ , \quad (30)$$

until diffusion arrests the cascade of scales. If diffusion is included, the smallest dynamically relevant thickness is obtained by balancing shear-induced thinning and diffusion. A standard estimate gives: $\ell_d \sim (\kappa/|\Omega_n'(\rho)|)^{1/3}$, which is the local Batchelor-type scale for shear-enhanced scalar gradients.

6. Toroidal variables and unwrapped representation. To make the analogy with toroidal transport explicit, introduce a radial action-like coordinate $\mathcal{I}$ and an angular coordinate θ. For an axisymmetric vortex a natural action variable is proportional to the area enclosed by a streamline:

$$\mathcal{I} = \ \rho^2/2 \ . \quad (31)$$

Then

$$\dot{\mathcal{I}} = 0 \ , \dot{\theta} = \Omega(\mathcal{I}) \ . \quad (32)$$

This is the canonical form of an integrable one-degree-of-freedom Hamiltonian system. The passive scalar equation becomes

$$\chi_t + \Omega(\mathcal{I})\chi_\theta = \kappa D_{\mathcal{I},\theta}\chi \quad (33)$$

where $D_{\mathcal{I},\theta}$ is the Laplacian expressed in action–angle coordinates. For the inviscid problem:

$$\chi(\mathcal{I}, \theta, t) = \chi_0(\mathcal{I}, \theta - \Omega(\mathcal{I})t) \quad (34)$$

In computations it is often useful to unwrap the local vortex into a rectangular domain. Define a periodic coordinate s, from the radial displacement relative to a reference ring ρ_0:

$$s = 1 + \alpha(\rho - \rho_0) \ (\mathrm{mod}\ 2) \ , \quad (35)$$

and retain

$$\theta = \tan^{-1}(\tilde{y}/\tilde{x}). \quad (36)$$

The scalar field then become $\chi(s, \theta, t)$. Spiral filaments in physical space appear as tilted bands in the (s, θ)-plane. The slope of these bands is controlled by the differential rotation:

$$d\theta/ds \sim (d\Omega/ds)t \ . \quad (37)$$

Thus, the unwrapped picture is not merely a visualization; it is a diagnostic of the local shear. The increasing inclination of scalar bands in (s, θ) measures the accumulation of phase differences between neighbouring radial labels.

7. Perturbation by neighbouring vortices. The isolated toroidal model is integrable and therefore cannot describe inter-vortex transport. To model a vortex street, one must include weak non-axisymmetric perturbations. We write:

$$\dot{\mathcal{I}}_n = \varepsilon F_n(\mathcal{I}_n, \theta_n, t), \dot{\theta_n} = \Omega_n(\mathcal{I}_n) + \varepsilon G_n(\mathcal{I}_n, \theta_n, t) \ , (38)$$

where $0 < \varepsilon \ll 1$ measures the strength of the external strain imposed by neighbouring vortices and the mean wake. In a frame moving downstream with speed

U_c, one also introduces the streamwise coordinate s of the vortex street:

$$\dot{s} = U_c + \varepsilon H_n(\mathcal{I}_n, \theta_n, t) \, . \qquad (39)$$

For $\varepsilon = 0$, the scalar remains confined to invariant curves $\mathcal{I}_n = const$. For $\varepsilon \neq 0$, the invariant curves are deformed. Near separatrices they may break, producing lobes through which scalar material is exchanged between vortex cores and the outer wake. The scalar equation in the perturbed action–angle variables is:

$$\partial\chi/\partial t + \varepsilon F_n(\partial\chi/\partial\mathcal{I}_n) + (\Omega_n(\mathcal{I}_n) + \varepsilon G_n)(\partial\chi/\partial\theta_n) + (U_c + \varepsilon H_n)(\partial\chi/\partial\, s) = \kappa\mathcal{D}\chi \, . \quad (40)$$

The small parameter ε has a clear physical meaning. If the characteristic velocity induced by the vortex core is $U_v \sim \Gamma_0/(2\pi r_c)$, and the characteristic strain due to a neighbouring vortex separated by distance d_v is $S \sim \Gamma_0/(2\pi d_v^2)$, then over a core radius r_c he perturbation velocity is of order Sr_c . Hence: $\varepsilon \sim Sr_c/U_v \sim (r_c/d_v)^2$. For compact vortices separated by more than a few core radii, ε is small inside the core but becomes order unity near the separatrix. This explains why the toroidal model is accurate in the vortex interior but must be supplemented by exchange dynamics near the boundary. A first-order expression for radial drift can be obtained by averaging over the fast angle. Suppose

$$F_n(\mathcal{I}, \theta, t) = \sum_{m,k} F_{mk}(\mathcal{I}) \exp\big(i(m\theta - k\omega_s t)\big) \, , \quad (41)$$

where ω_s is the vortex shedding frequency. Away from resonances, the average drift vanishes at first order:

$$\langle\dot{\mathcal{J}}\rangle = \varepsilon\langle F\rangle_\theta = 0 \, . \qquad (42)$$

Near resonances satisfying

$$m\,\Omega(\mathcal{J}) \simeq k\omega_s \, , \qquad (43)$$

slow secular exchange becomes possible. Thus scalar leakage is expected to be strongest near resonant shells and separatrix layers.

8. Reduced scalar-filament equation. Consider a scalar filament inside a vortex. Its centreline may be parameterized by the angular variable θ, while its local transverse thickness is $\ell(\theta, t)$. The simplest reduced description keeps only the stretching rate σ, the leakage rate λ, ands diffusion. Let $C(\theta, t)$ be the scalar amplitude along the filament. Then a one-dimensional model is

$$C_t + \Omega(\mathcal{J}_0)C_\theta = D_\ell C_{\theta\theta} - \lambda C \, , \qquad (44)$$

where D_ℓ is an effective diffusivity along the filament and λ represents loss from the local vortex to the outer wake. The thickness evolves according to

$$d\ell/dt = -\sigma(t)\ell + \kappa/\ell \, , \qquad (45)$$

where $\sigma(t) \sim |\Omega'(\mathcal{J}_0)|/(1 + |\Omega'(\mathcal{J}_0)|t)$ for pure shear winding. In the early inviscid stage,

$$\ell(t) \sim \ell_0/(1 + |\Omega'(\mathcal{J}_0)|t) \, . \qquad (45^*)$$

In the diffusive stage, the balance $d\ell/dt \approx 0$ gives: $\ell(t) \sim (\kappa/\sigma(t))^{1/2}$. A more Eulerian reduced equation follows from expanding the scalar field in local sheared coordinates. Let

$$\Theta = \theta - \Omega(\mathcal{I})t \, . \qquad (46)$$

Then

$$\partial_\jmath|_\theta = \partial_\jmath|_\Theta - t\Omega'(\mathcal{J})\,\partial_\Theta \qquad (47)$$

Consequently, diffusion becomes anisotropically amplified:

$$\chi_t = \kappa\left[\partial_\jmath^2 - 2t\Omega'(\mathcal{I})\partial_{\jmath\Theta} + t^2\big(\Omega'(\mathcal{I})\big)^2\partial_\Theta^2 + \cdots\right]\chi \, . \quad (48)$$

The term proportional to t^2, is the mathematical expression of shear-enhanced dissipation. It shows that even small κ becomes effective after the scalar has been wound into sufficiently fine filaments.

9. Global capture–stretch–escape map. The vortex street consists of a sequence of coherent vortices. Instead of following the scalar continuously, one may construct a discrete map from one vortex encounter to the next. Let M_n denote the scalar distribution immediately after interaction with the n-th vortex. Then:

$$M_{n+1} = \mathcal{E}_{n+1}\mathcal{A}_n C_n M_n \, . \qquad (49)$$

Here C_n is a capture operator, $\mathcal{A}_n$ is the intra-vortex advection and filamentation operator, and $\mathcal{E}_{n+1}$ is the escape and transfer operator. The advection operator is locally toroidal:

$$(\mathcal{A}_n\chi)(\mathcal{I}, \theta) = \chi(\mathcal{I}, \theta - \Omega_n(\mathcal{I})T_n) \qquad (50)$$

where T_n is the residence time of scalar material in the vortex. The escape operator may be modelled by a probability kernel K_n:

$$(\mathcal{E}_n\chi)(\mathcal{I}', \theta') = \int K_n(\mathcal{I}', \theta' \mid \mathcal{I}\,, \theta)\,\chi(\mathcal{I}, \theta)d\mathcal{I}\,d\theta \, . \quad (51)$$

A simple leakage model is:

$$K_n(\mathcal{I}', \theta' \mid \mathcal{I}\,, \theta) = p_n(\mathcal{I}, \theta)\,\delta(\mathcal{I}' - \mathcal{I}_\varepsilon)\,\delta(\theta' - \theta_\varepsilon) + [1 - p_n(\mathcal{I}, \theta)]\,\delta(\mathcal{I}' - \mathcal{I})\,\delta(\theta' - \theta) \quad (52)$$

where p_n is the probability of escape during one turnover. The probability is small in the vortex core and large near the separatrix. A useful asymptotic form is:Type equation here.

$$p_n(\mathcal{I}, \theta) \sim \exp[-\Delta\mathcal{J}(\mathcal{I})/\varepsilon]\;P(\theta, t) \, , \quad (53)$$

where $\Delta\mathcal{J}(\mathcal{I})$ represents the barrier in the action variable, and $P(\theta, t)$ describes the dependence on angle and time, and where $\Delta\mathcal{I}$ measures the action distance from the separatrix. This expression captures the exponentially weak leakage from the core and the strong exchange near broken separatrices.

Thus, the global scalar field in the wake is therefore not merely a collection of isolated spirals. It is a concatenation of local winding events connected by escape kernels. The global stretching factor after N vortex encounters is approximately:

$$\Lambda_N \sim \prod_{n=1}^{N}(1 + |\Omega_n'(\mathcal{J}_n)|T_n)\,\Lambda_{\epsilon,n} \, , \quad (54)$$

where $\Lambda_{\epsilon,n}$ is the stretching associated with escape and inter-vortex strain. Taking logarithms gives the finite-time Lyapunov estimate:

$$\lambda_N \sim (1/\sum_n T_n)\sum_{n=1}^{N}\log\big[(1 + |\Omega_n'(\mathcal{J}_n)|T_n)\,\Lambda_{\epsilon,n}\big] \, . \quad (55)$$

This formula separates local toroidal winding from global chaotic exchange.

10. Gradient growth and filament thickness. The numerical diagnostics associated with the model are the scalar gradient magnitude and the transverse filament thickness. The gradient magnitude is

$$|\nabla\,\chi| = \sqrt{\chi_x^2 + \chi_y^2} \, . \qquad (56)$$

In a reconstructed particle field, the derivatives are computed after kernel smoothing. The maximum gradient is

$$G_{max}(t) = \max_{x,y}|\nabla\,\chi\,(x, y, t)|. \qquad (57)$$

For pure differential rotation, the gradient grows algebraically:

$$G_{max}(t) \sim G_0(1 + |\Omega'|t). \qquad (58)$$

In a vortex street, however, strain layers and repeated vortex encounters may produce an exponential envelope:

$$G_{max}(t) \sim G_0\, e^{\sigma t} \qquad (59)$$

where σ is an effective stretching rate. The exponential law should not be interpreted as proof of fully developed turbulence; it is a finite-time consequence of repeated stretching and folding by coherent vortices. The transverse filament thickness may be estimated from a half-maximum width of scalar concentration in a local cross-section. If $\ell_\perp(t)$ denotes this width, then the toroidal model predicts

$$\ell_\perp(t) \sim \ell_0/(1+\alpha t) \quad (60)$$

during the shear-winding stage. In the vortex street, inter-vortex strain can accelerate thinning:

$$\ell_\perp(t) \sim \ell_0 e^{-\sigma t}\,, \quad (61)$$

until diffusion imposes the cutoff: $\ell_\perp \gtrsim \ell_d$. Thus, A combined empirical law is therefore:

$$\ell_\perp(t) \sim \max\{(\ell_0/(1+\alpha t))e^{-\sigma_\epsilon t}, \ell_d\} \quad (62)$$

where σ_ϵ measures additional stretching due to inter-vortex exchange.

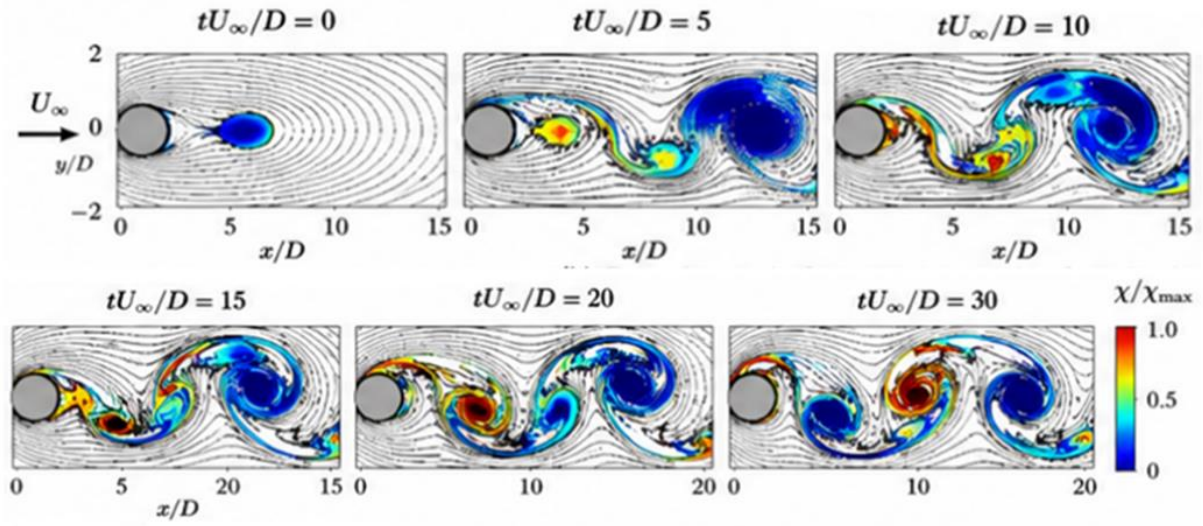

Fig. 1. Time evolution of a passive scalar in the wake behind a cylinder: vortex capture, spiral winding, and inter-vortex exchange in the von Kármán vortex street.

11. Relation to amplitude-equation thinking. The local toroidal transport model may be placed in a broader family of reduced hydrodynamic descriptions. In long-wave theories of shear flow, one often derives an amplitude equation for a slowly varying large-scale mode. In the present scalar-transport problem, the analogous amplitude is not a velocity instability amplitude but a coarse-grained scalar or filament-density amplitude.

Let $A(s,t)$ denote a slowly varying measure of scalar content along the wake. A minimal transport equation is:

$$A_t + U_c A_s = D_{eff} A_{ss} - \partial_s\big(V_{drift} A\big) - \Lambda\, A + Q\,. \quad (63)$$

Here D_{eff} is an effective longitudinal diffusivity generated by repeated vortex encounters, V_{drift} is a correction to mean convection, Λ is a net escape or dilution rate, and Q is a scalar source. This equation describes downstream redistribution but not the internal filament geometry.

To include filamentation, introduce a second field $B(s,t)$, representing mean scalar-gradient intensity, for instance:

$$B(s,t) = \langle |\nabla \chi|^2 \rangle_{cell}\,. \quad (64)$$

A phenomenological closure is:

$$B_t + U_c B_s = D_B B_{ss} + 2\sigma(s,t)B - 2\kappa C_B B^2 - \Lambda_B B\,. \quad (65)$$

The production term $2\sigma B$ represents stretching; the nonlinear sink $2\kappa C_B B^2$ represents diffusive destruction of gradients at small scales; and Λ_B represents dilution by escape from coherent structures. Such an equation is not universal, but it translates the geometric toroidal mechanism into an amplitude-equation framework.

A more direct analogue of reduced shear-flow theories is obtained near a separatrix. Let η be the coordinate normal to the separatrix and ξ the coordinate along it. The scalar equation in a thin exchange layer has the form:

$$\Theta_t + S\eta\Theta_\xi + V(\xi,t)\,\Theta_\eta = \kappa\Theta_{\eta\eta}\,, \quad (66)$$

where $S\eta$ is the local shear and V is a perturbation-induced normal velocity. This equation is structurally similar to boundary-layer or defect equations in which outer motion supplies a nonlocal forcing and inner dynamics regularizes sharp gradients. In the present context, the layer is not a vorticity defect but a scalar-exchange defect surrounding a coherent vortex.

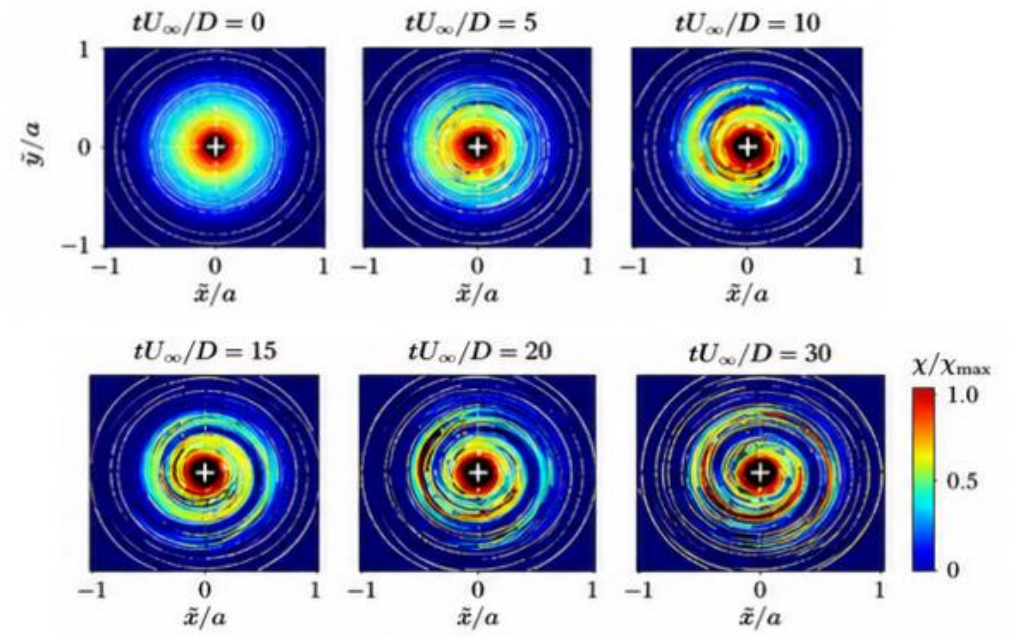

Fig. 2. Evolution of the passive scalar distribution in the co-moving vortex frame: winding of an initially compact patch into spiral filaments due to differential rotation.

12. Non-dimensional groups. The model contains several dimensionless parameters. The first is the Reynolds number of the wake:

$$Re = U_\infty D/\nu \,, \tag{67}$$

which controls vortex shedding and the persistence of coherent structures. The second is the Péclet number:

$$Pe = U_\infty D/\kappa \,, \tag{68}$$

which controls scalar filament survival.

The third is a vortex-strength parameter,

$$\Gamma^* = \Gamma_0/U_\infty D \,. \tag{69}$$

The fourth is a core-spacing parameter:

$$\delta = r_c/L \,, \tag{70}$$

and the fifth is a row-spacing parameter:

$$\beta = a/L \,. \tag{71}$$

The local shear rate inside a vortex is characterized by:

$$S_\upsilon = \max_\rho |\rho\, \Omega'(\rho)| \,. \tag{72}$$

A corresponding local scalar Péclet number is:

$$Pe_\upsilon = S_\upsilon r_c^2/\kappa \,. \tag{73}$$

When $Pe_\upsilon \gg 1$, the scalar forms thin spirals before diffusion smooths them. When $Pe_\upsilon = \mathcal{O}(1)$, diffusion suppresses fine filamentation and the toroidal mechanism is weak. The strength of inter-vortex perturbation is measured by:

$$\varepsilon \sim (r_c/d_\upsilon)^2 \,, \tag{74}$$

where d_υ is the distance to the nearest neighbouring vortex. The asymptotic ordering underlying the local theory is: $Pe_\upsilon \gg 1$, $\varepsilon \ll 1$ inside the core, with $\varepsilon = \mathcal{O}(1)$ allowed in the separatrix layer.

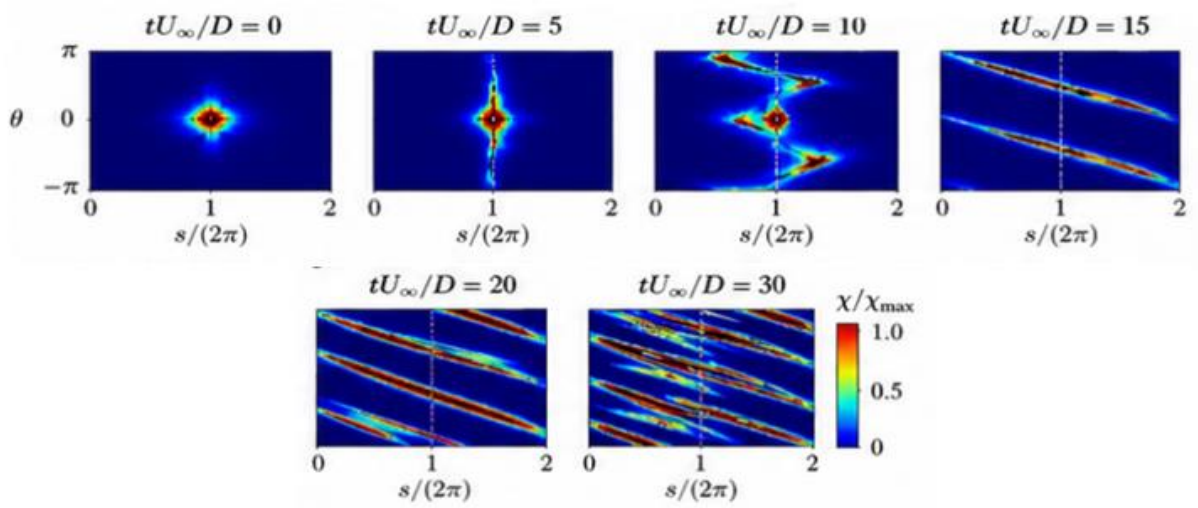

Fig. 3. Unwrapped representation of the scalar field in (s,θ) coordinates: differential rotation leads to the formation of inclined bands whose slope increases with time and reflects the local shear..

13. Mathematical statement of the model hierarchy. The complete reduced model can be summarized as follows. The full passive-scalar problem is:

$$\chi_t + \mathbf{u} \cdot \nabla \chi = \kappa \Delta \chi \quad (75)$$

with $\mathbf{u} = U_\infty \mathbf{e_x} + \sum_n \mathbf{u}_n + \mathbf{u}_b$ (76). Near the n-th vortex, introduce local action–angle variables $(\mathcal{J}_n, \theta_n)$. The local equations are:Type equation here.

$$\begin{aligned} \dot{\mathcal{J}}_n &= \varepsilon F_n(\mathcal{J}_n, \theta_n, t) \\ \dot{\theta}_n &= \Omega_n(\mathcal{J}_n) + \varepsilon G_n(\mathcal{J}_n, \theta_n, t) \\ \dot{s} &= U_n + \varepsilon H_n(\mathcal{J}_n, \theta_n, t) \end{aligned} \quad (77)$$

The scalar equation becomes:

$$\chi_t + \varepsilon F_n \chi_{\mathcal{J}_n} + (\Omega_n + \epsilon G_n)\chi_{\theta_n} + (U_c + \varepsilon H_n)\chi_s = \kappa \mathcal{D}_n \chi \, . \quad (78)$$

It should be noted that in the limit of the integrable core ($\varepsilon = 0$):

$$\chi_t + \Omega_n(\mathcal{J}_n)\chi_{\theta_n} = 0, \quad (79)$$

which corresponds to purely toroidal winding in the absence of inter-vortex exchange. Thus, here, in the integrable core limit we have:

$$\chi(\mathcal{J}_n, \theta_n, t) = \chi_0(\mathcal{J}_n, \theta_n - \Omega_n(\mathcal{J}_n)\, t) \, . \quad (80)$$

In the weakly perturbed case, scalar leakage is determined by resonances and separatrix splitting. In a global discrete representation:

$$M_{n+1} = \mathcal{E}_{n+1}\mathcal{A}_n C_n M_n \, . \quad (81)$$

The principal observables are: $G_{max}(t) = \max|\nabla\chi|$, $\ell_\perp(t) =$ *local half-maximum filament width* and

$$\mathcal{M}(t) = \int |\nabla\chi|^2 dxdy \, , \quad (82)$$

where $\mathcal{M}$ is a scalar-gradient or mixing diagnostic. The expected asymptotic behaviour is

$$G_{max}(t) \sim G_0 e^{\sigma t} \quad (83)$$

for repeated vortex-street stretching, and $\ell_\perp(t) \sim \max\{\ell_0 e^{-\sigma t}, \ell_d\}$ (84), with algebraic thinning replacing exponential thinning inside a single isolated vortex.

14. Interpretation of numerical visualizations. The computational visualization associated with this model contains several panels, each corresponding to a level of the theory. The global scalar field $\chi(x, y, t)$ shows the passive scalar being advected downstream and distorted by the alternating vortices. At early times the scalar remains a compact cloud. At intermediate times it is captured by one or more vortex cores and wrapped into spiral-like structures. At later times the scalar is distributed through the wake, with thin filaments connecting neighbouring vortical regions.

A co-moving frame centered on a single vortex isolates the local toroidal transport mechanism. In this frame, the vortex core forms a nearly closed recirculation region, within which scalar contours wrap around the centre and progressively tighten due to differential rotation. This behaviour is described mathematically by:

$$\chi_t + \Omega(\rho)\chi_\phi = \kappa \Delta \chi \quad (85)$$

with weak perturbations accounting for inter-vortex interactions.

The unwrapped (s, θ) representation transforms the spiral structure into tilted bands. The progressive increase in the inclination of these bands provides direct evidence of shear-induced phase mixing. If the bands become broken, folded, or discontinuous, this indicates that the perturbation terms F and G are no longer negligible and that inter-vortex exchange has entered the local dynamics

The time series of $\max|\nabla\chi|$ quantifies the generation of small scales. Growth of this quantity indicates that scalar material is being stretched into increasingly sharp filaments. The time series of the transverse thickness $\ell_\perp$ measures the complementary contraction of these filaments. Together, these diagnostics test the predicted relation

$$G_{max}(t)\ell_\perp(t) \approx const \quad (86)$$

in the purely advective, locally area-preserving regime. Deviations from this relation indicate diffusion, leakage, or nonlocal stretching.

15. Discussion.

The toroidal extension proposed here should be interpreted as a geometric theory of transport rather than a complete model of the wake. It does not aim to predict the shedding frequency from first principles, nor does it provide a dynamically self-consistent Navier–Stokes solution for the vortex street. Instead, it assumes a prescribed kinematic vortex street and investigates how passive scalar material is transported within it. This separation is advantageous, as scalar transport is often governed more directly by the geometry of coherent structures than by the mechanisms responsible for their formation.

The model clarifies why a von Kármán vortex street mixes more effectively than a single steady vortex. A single steady vortex can stretch a scalar patch into a spiral, but in the absence of radial exchange the scalar remains confined on invariant curves. The resulting process is primarily filamentation rather than global mixing. In contrast, a vortex street introduces two essential mechanisms. First, neighbouring vortices generate strain that deforms invariant curves. Second, periodic shedding and downstream convection create repeated opportunities for capture and release. As a result, the scalar undergoes a sequence of local toroidal windings interspersed with separatrix-crossing events. This sequence significantly enlarges the accessible region in phase space compared to that of a single isolated vortex.

The model also explains why the strongest scalar gradients are expected near vortex boundaries and inter-vortex strain layers. Within the vortex core, the scalar is wound coherently. Near the separatrix, however, small perturbations can separate nearby trajectories and eject filaments into the wake. The interface between the coherent core and the surrounding strain field therefore becomes the natural location for the formation of sharp gradients.

From a mathematical perspective, the vortex street transforms an integrable action–angle system into a weakly non-integrable, time-periodic Hamiltonian system. In the unperturbed case, invariant curves $\mathcal{J} = const$ are preserved. In the perturbed case, resonances, separatrix splitting, and chaotic layers emerge. The passive scalar provides a direct visual representation of these structures: smooth spirals correspond to regular winding, while elongated inter-vortex filaments reflect chaotic exchange.

16. Conclusion.

We have developed an extension of a toroidal transport model to passive-scalar motion in a von Kármán vortex street. The main result is a hierarchy of reduced equations connecting three levels of description. At the local level, each coherent vortex contains nearly closed streamlines and supports toroidal-like differential rotation. In this region, an initially localized scalar patch is wound into a spiral, with gradient growth controlled by $\Omega'(\mathcal{J})$, and transverse thinning governed by $\ell_\perp(t) \sim [1 + |\Omega'|t]^{-1}$. At the intermediate level, neighbouring vortices perturb the local invariant curves and generate radial leakage, resonant exchange, and separatrix-layer stretching. At the global level, the wake acts as a sequence of capture, filamentation, escape and recapture events.

The mathematical model may be summarized by the perturbed action–angle system

$\dot{\mathcal{J}}_n = \varepsilon F_n(\mathcal{J}_n, \theta_n, t)$, $\dot{\theta}_n = \Omega_n(\mathcal{J}_n) + \varepsilon\, G_n(\mathcal{J}_n, \theta_n, t)$,

coupled to the passive-scalar equation:

$\chi_t + \varepsilon F_n \chi_{\mathcal{J}_n} + (\Omega_n + \varepsilon G_n)\chi_{\theta_n} + (U_c + \varepsilon H_n)\chi_s = \kappa \mathcal{D}_n \chi$

This formulation clarifies the sense in which the toroidal model applies to the vortex street. It does not represent the entire wake as a single torus; rather, each coherent vortex is treated as a local toroidal transport cell, while the remainder of the street acts as a weak but dynamically decisive perturbation. The resulting framework provides a compact mathematical interpretation of Lagrangian simulations and scalar-field visualizations in wakes: scalar patches are captured by vortices, wound into thin filaments, expelled through deformed separatrices, and transported downstream through a sequence of coherent structures.

A natural next step is to compare the reduced model quantitatively with particle-based simulations by measuring $\Omega(\mathcal{J})$, estimating ε, identifying separatrix layers, and fitting the observed evolution of $G_{max}(t)$ and $\ell_\perp(t)$. Such a comparison would convert the present geometric theory into a predictive reduced model of passive-scalar mixing in vortex streets.

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FACTORS AFFECTING LIFE EXPECTANCY WORLDWIDE

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Abstract

The purpose of this study is to identify the factors affecting life expectancy in 207 countries and understanding how these factors effects to human longevity. Using international data from the World Bank, World Population Review, and other open sources, we applied correlation analysis and regression analysis to examine the indicators influencing life expectancy. A two-factor regression model was created by calculating correlation coefficient using Microsoft Excel. The results showed that the influence of various factors on a person's life expectancy varies depending on regional characteristics, the level of development and the social status of countries. Among them, it was found that factors such as gross domestic product, education level and lifestyle play a special role. These indicators were divided into 5 groups for consideration.

Keywords: life expectancy, regression model, corruption, gdp, factor

1. Introduction

Since ancient times, people have striven to live longer. In recent years, increaing life expectancy has become a goal of leading countries, so it is important to accurately assess the socio-economic factors that influence this Indicator. Genetics determine only a quarter of the lifespan. Therefore, people can increase lifespan by taking certain actions. In this regard, life expectancy reflects not only the state of health, but also economic and social well-being, the lifestyle of the population, the quality of the environment and so on. However, the importance of these factors is very likely to show different results in countries with different levels of development. Globally, a country's gross domestic product, happiness index, and average wage play a significant role in increasing life expectancy. And, as expected, the level of corruption and inflation has a negative impact. This shows that the higher the level of corruption and inflation in a country, the shorter its life expectancy.

1.1 Literature Matrix

Title	Author(s), Year	Methodology	Key Findings	Connection to our work
Factors affecting life expectancy in Kazakhstan	A.Zh. Panzabekova, Ivan E. Digel 2020	The study is based on regression and correlation analysis. Data were selected based on two criteria: availability of long-term statistical data and potential impact on life expectancy. A two-factor power regression model was constructed using Microsoft Excel.	The study used regression models to analyze the impact of socio-economic factors on life expectancy in the regions of Kazakhstan. The results show that economic factors have the most significant influence, while some relationships require further research.	We used the same methods as in the article, but not just for Kazakhstan's regions, but for the entire world. And you can see a trend that within individual countries and within each country, the indicators vary according to certain logics.
Factors Influencing Life Expectancy: Global Evidence from 125 Countries	Gabriel Hoh Teck Ling*, Noradila Rusli, Teh Hock Heng, Tan Kean Poh, Sumaia Faisal, Hu Jianke, Bai Ni, Mohemed S Abdullh Mohamed, 2025	The study uses secondary data from WHO, World Bank, and UN for 125 countries. Life expectancy is modeled as the dependent variable, with socioeconomic, healthcare, lifestyle, and environmental factors as predictors. Multiple linear regression in SPSS analyzes the relationships and significance of these determinants.	The study identified alcohol consumption, happiness, CO2 emissions, and PM2.5 air pollution as significant determinants of life expectancy, emphasizing the need for targeted policies in these areas. While BMI, GDP per capita, corruption perception, and government health expenditure were not significant in the regression model, they may still influence life expectancy in other contexts or analyses.	This work gives us a full understanding of what we're doing and allows us to compare our results with theirs. It's noticeable that the number of countries we work with plays a significant role in correlation indicators.
Modelling of life expectancy in the world	V. A. Shtun, 2021	Econometric analysis using multiple linear regression based on cross-country data (126 countries). Statistical testing of variables and model diagnostics were applied to determine significant factors affecting life expectancy.	The study found that life expectancy is significantly influenced by access to clean drinking water, government health expenditure, vaccination coverage, electricity access, and GDP per capita. Negative effects were found for alcohol consumption and CO_2 emissions. Some variables such as unemployment, education level, and smoking were not statistically significant in the global model.	This study supports our diploma research by demonstrating how statistical modeling can be used to analyze determinants of life expectancy across countries. It provides methodological support for our machine learning approach and helps justify the selection of socioeconomic, behavioral, and environmental variables used in our life expectancy prediction model.

2. Methodology

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

For each independent variable, a simple linear regression model was constructed: $\widehat{v_i} = m_1 + m_2 u_i$ (1)

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

To examine the relationship between life expectancy and selected factors, the correlation analysis is

applied. In this study, the simple linear correlation coefficient is used to measure the strength and direction of the relationship between variables.

The correlation coefficient is calculated as follows:

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

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

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

$$K^2 = \frac{\sum_{i=0}^{n} (\hat{v}_i - \overline{v})^2}{\sum_{i=0}^{n} (v_i - \overline{v})^2} \quad (3)$$

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

3. Regression analysis of Factors Affecting Life Expectancy

A data set was compiled for 207 countries. The following variables were included in the analysis: smoking rate, drug prevalence, obesity, gross domestic product per capita (GDP), happiness index, gender equality index, meat consumption, corruption, education, average salary, inflation, CO2 emissions, and alcohol consumption. Python programming language was used primarily to process the data set. This process included data loading, cleaning missing values, normalizing indicators and combining various sources into a single table containing 207 countries.

Table 1.

Dataset of 207 countries used in the analysis

Country	LE(v)	smo(u_1)	nar(u_2)	obe(u_3)	gdp(u_4)	happ(u_5)	geq(u_6)	mt(u_7)	corr(u_8)	ed(u_9)	aversal(u_{10})	infl(u_{11})	co2(u_{12})	alc(u_{13})
Afghanistan	66.29	21.3	1.36	17.7	2202.0	1.72	0.715	9.6	16.0	0.381	0.172	5.7	0.14	0.4
Albania	79.78	20.7	0.7	26.6	23488.0	5.3	0.763	47.9	39.0	0.739	0.511	2.3	1.59	5.9
Algeria	76.48	21.1	2.46	24.2	17553.0	5.36	0.614	22.4	34.0	0.664	0.356	1.5	3.89	0.8
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Thailand	76.56	18.3	1.11	14.5	24708.0	5.98	0.728	54.9	33.0	0.426	0.615	-0.88	3.94	5.4
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Zambia	66.53	14.1	1.19	11.6	4224.0	3.5	0.707	29.2	37.0	0.313	0.182	7.5	0.46	5.5
Zimbabwe	63.06	10.4	2.31	9.4	3922.0	3.34	0.747	54.9	22.0	0.549	0.169	3.8	0.64	6.4

The correlation coefficients were calculated using formula 2. All calculated correlation coefficients between the studied factors are presented in Table 2.

Table 2.

Correlation coefficients

Indicators	Correlation coefficient (k)
smo	0,167
nar	0,077
obe	0,3
gdp	0,714
happ	0,604
geq	0,357
mt	0,573
corr	-0,561
ed	0,274
aversal	0,63
infl	-0,126
co2	0,314
alc	0,205
pop	-0,017
area	0,02

Since life expectancy can vary depending on continental factors, countries were grouped by continents to analyze which variables have the greatest impact on life expectancy in each country group. Population and Country Area indicators, which showed the lowest correlation, were not included in the analysis. Correlation coefficients were calculated using formula 2. The results for Asian countries are presented in Table 3.

Table 3.

Correlation between life expectancy and factors in Asia

Central Asia	k	k^2	East Asia	k	k^2	West Asia	k	k^2	South-East As	k	k^2	South Asia	k	k^2
Smo	0,57	0,33	Smo	-0,55	0,31	Smo	-0,41	0,18	Smo	-0,51	0,26	Smo	0,27	0,08
Nar	0,53	0,28	Nar	-0,19	0,03	Nar	0,07	0,01	Nar	-0,24	0,06	Nar	-	-
Obe	-0,05	0,01	Obe	-0,60	0,37	Obe	0,45	0,20	Obe	0,56	0,31	Obe	-0,21	0,05
Gdp	0,59	0,36	Gdp	0,51	0,26	Gdp	0,79	0,63	Gdp	0,84	0,72	Gdp	0,91	0,84
Happ	0,7	0,5	Happ	0,37	0,01	Happ	0,54	0,30	Happ	0,70	0,50	Happ	0,49	0,24
Geq	-0,15	0,025	Geq	-0,51	0,26	Geq	-0,15	0,02	Geq	-	-	Geq	0,01	0,00
Mt	0,6	0,36	Mt	0,25	0,07	Mt	0,74	0,48	Mt	-0,29	0,08	Mt	0,84	0,71
Corr	-0,91	0,84	Corr	-0,88	0,34	Corr	-0,58	0,34	Corr	-0,53	-0,53	Corr	-0,33	0,11
Ed	0,59	0,36	Ed	-0,66	0,44	Ed	0,26	0,07	Ed	-0,49	0,24	Ed	0,36	0,13
Aversal	0,16	0,026	Aversal	0,97	0,94	Aversal	0,59	0,35	Aversal	0,83	0,70	Aversal	-	-
Infl	0,69	0,5	Infl	-0,80	0,65	Infl	0,03	0,01	Infl	-0,67	0,46	Infl	-0,56	0,31
Co2	0,3	0,093	Co2	0,35	0,12	Co2	0,68	0,46	Co2	0,59	0,34	Co2	0,70	0,49
Alc	0,11	0,02	Alc	0,16	0,03	Alc	-	-	Alc	-0,14	0,02	Alc	0,43	0,18

Central Asia: Kazakhstan - 74,53
Kyrgyzstan - 71,82
Tajikistan - 71,93
Turkmenistan - 70,2
Uzbekistan - 72,53

East Asia: China - 78,02
Hong Kong - 85,63
Japan - 84,85
Macau - 83,23
Mongolia - 71,99
North Korea - 73,74
South Korea -84,43

West Asia: Bahrain - 81,42
Turkey - 77,42
Kuwait - 80,6
Oman - 80,25
Saudi Arabia - 78,98
Qatar - 82,55
United Arab Emirates - 83,07
Yemen - 69,44
Armenia - 75,85
Azerbaijan - 74,58
Georgia - 74,66
Iran - 77,85
Iraq - 72,42
Israel - 82,73
Jordan - 77,98
Lebanon - 77,95
Palestine - 69,21
Syria - 72,56
Cyprus - 81,82
Egypt - 71,81

South-East Asia: Brunei - 75,5
Timor-Leste - 67,9
Vietnam - 74,74
Indonesia - 71,29
Cambodia - 70,82
Laos - 69,22
Malaysia - 76,82
Myanmar - 67,1
Singapore - 83,86
Thailand - 76,56
Philippines - 69,95

South Asia: India - 72,24
Pakistan - 67,8
Bangladesh - 74,93
Afghanistan - 66,29
Bhutan - 73,26
Maldives - 81,29
Nepal - 70,64
Sri Lanka - 77,67

Table 4.

Correlation between life expectancy and factors in Europe

West Europe	k	k^2	East Europe	k	k^2	North Europe	k	k^2	South Europe	k	k^2
Smo	0,14	0,02	Smo	0,06	0,04	Smo	-0,88	0,77	Smo	0,07	0,01
Nar	-0,27	0,07	Nar	-0,52	0,27	Nar	0,35	0,12	Nar	0,29	0,08
Obe	-0,83	0,68	Obe	0,47	0,22	Obe	-0,85	0,72	Obe	-0,42	0,18
Gdp	0,65	0,43	Gdp	0,76	0,57	Gdp	0,81	0,66	Gdp	0,87	0,76
Happ	0,13	0,02	Happ	0,31	0,09	Happ	0,81	0,66	Happ	-	-
Geq	-0,58	0,34	Geq	-0,45	0,20	Geq	0,67	0,45	Geq	-0,08	0,01
Mt	-0,52	0,27	Mt	0,20	0,04	Mt	0,24	0,06	Mt	0,32	0,10
Corr	-0,73	0,53	Corr	0,54	0,29	Corr	-0,83	0,69	Corr	-0,53	0,28
Ed	0,50	0,25	Ed	0,49	0,24	Ed	0,27	0,07	Ed	0,03	0,01
Aversal	-0,16	0,03	Aversal	0,46	0,21	Aversal	0,88	0,77	Aversal	0,76	0,58
Infl	0,45	0,20	Infl	-0,31	0,09	Infl	-0,19	0,04	Infl	0,25	0,06
Co2	-0,48	0,23	Co2	-	-	Co2	0,41	0,17	Co2	-0,04	0,01
Alc	-0,17	0,03	Alc	0,05	0,01	Alc	-0,68	0,46	Alc	-0,46	0,21

West Europe: Belgium - 82,27
United Kingdom - 81,45
Germany - 81,54
Ireland - 82,58
Luxembourg - 82,36
Monaco - 86,5
Netherlands - 82,3
France - 83,46
Switzerland - 84,09
Austria - 82,12

East Europe: Belarus - 74,62
Bulgaria - 75,8
Hungary - 77,18
Moldova - 71,33
Poland - 78,81
Russia - 73,34
Romania - 76,09
Slovakia - 78,49
Ukraine - 74,69
Czechia - 79,97

North Europe: Denmark - 82,09
Iceland - 83,01
Latvia - 76,33
Lithuania - 76,17
Norway - 83,46
Finland - 82,08
Sweden - 83,42
Estonia - 79,31

South Europe: Albania - 79,78
Andorra - 84,19
Bosnia and Herzegovina - 78,04
Greece - 82,03
Italy - 83,87
Spain - 83,8
Malta - 83,47
Portugal - 82,55
San Marino - 85,82
Serbia - 76,94
Montenegro - 77,25
Croatia - 78,75

Table 5.

Correlation between life expectancy and factors in America and Oceania

Central America	k	k^2	North America	k	k^2	South America	k	k^2	Oceania	k	k^2
Smo	-0,43	0,18	Smo	0,23	0,05	Smo	-0,24	0,06	Smo	-0,64	0,41
Nar	-0,38	0,14	Nar	0,48	0,23	Nar	-0,56	0,31	Nar	0,56	0,32
Obe	0,3	0,19	Obe	0,34	0,12	Obe	0,48	0,23	Obe	-0,29	0,08
Gdp	0,86	0,73	Gdp	0,49	0,24	Gdp	0,60	0,37	Gdp	0,83	0,70
Happ	0,58	0,34	Happ	-	-	Happ	0,60	0,36	Happ	-	-
Geq	0,7	0,49	Geq	-	-	Geq	-	-	Geq	-	-
Mt	0,81	0,65	Mt	0,44	0,20	Mt	0,27	0,07	Mt	0,21	0,04
Corr	-0,63	0,40	Corr	-0,43	0,18	Corr	-0,55	0,31	Corr	-	-
Ed	-0,14	0,02	Ed	0,37	0,14	Ed	-0,13	0,02	Ed	0,52	0,27
Aversal	0,73	0,54	Aversal	0,12	0,01	Aversal	0,52	0,27	Aversal	0,87	0,76
Infl	-0,62	0,38	Infl	-0,52	0,27	Infl	-0,27	0,07	Infl	-	-
Co2	0,74	0,55	Co2	0,41	0,17	Co2	-	-	Co2	0,07	0,01
Alc	0,39	0,15	Alc	0,35	0,12	Alc	-0,09	0,01	Alc	-0,86	0,74

Central America: Belize - 73,74
Costa Rica - 81
El Salvador - 72,3
Guatemala - 72,75
Honduras - 73,04
Nicaragua - 75,1
Panama - 79,77

North America: Greenland - 70,19
Canada - 82,72
United States - 79,46
Mexico - 75,26
Antigua and Barbuda - 77,77
Bahamas - 74,71
Barbados - 76,33
Cuba - 78,26
Dominica - 71,29
Dominican Republic - 73,87
Grenada - 75,37
Haiti - 65,12
Honduras - 73,04
Jamaica - 71,61
Saint Kitts and Nevis - 72,28
Saint Lucia - 72,85
Saint Vincent and the Grenadines - 71,38
Trinidad and Tobago - 73,62

South America: Argentina - 77,54
Bolivia - 68,74
Brazil - 76,02
Chile - 81,36
Colombia - 77,91
Ecuador - 77,58
Guyana - 70,32
Paraguay - 73,98
Peru - 77,94
Suriname - 73,76
Uruguay - 78,29
Venezuela - 72,67

Oceania: Australia- 84,07
Fiji - 67,46
Kiribati - 66,6
Marshall Islands - 67,08
Micronesia - 67,36
Nauru - 62,28
New Zealand - 82,24
Palau - 69,38
Papua New Guinea - 66,26
Samoa - 71,83
Solomon Islands - 70,69
Tonga - 73,07
Tuvalu - 67,26
Vanuatu - 71,65

Table 5.

Correlation between life expectancy and factors in Africa

North Africa	k	k^2	West Africa	k	k^2	Central Africa	k	k^2	East Africa	k	k^2	South Africa	k	k^2
Smo	-0,05	0,01	Smo	0,15	0,02	Smo	0,51	0,26	Smo	-	-	Smo	-0,46	0,21
Nar	-0,37	0,14	Nar	-0,43	0,19	Nar	0,41	0,17	Nar	0,17	0,03	Nar	-0,19	0,04
Obe	0,10	0,01	Obe	0,44	0,20	Obe	0,97	0,94	Obe	0,43	0,19	Obe	-0,08	0,01
Gdp	0,62	0,39	Gdp	-	-	Gdp	0,84	0,71	Gdp	0,71	0,49	Gdp	0,92	0,85
Happ	-0,35	0,13	Happ	0,04	0,01	Happ	0,30	0,10	Happ	0,05	0,01	Happ	0,42	0,18
Geq	0,22	0,05	Geq	0,32	0,10	Geq	0,60	0,36	Geq	-0,11	0,01	Geq	0,66	0,43
Mt	0,19	0,04	Mt	0,50	0,26	Mt	0,56	0,31	Mt	0,42	0,18	Mt	0,57	0,33
Corr	-0,87	0,76	Corr	-0,33	0,11	Corr	-0,51	0,27	Corr	-0,65	0,43	Corr	-0,56	0,32
Ed	0,23	0,06	Ed	0,72	0,53	Ed	0,93	0,87	Ed	-0,15	0,02	Ed	-0,16	0,03
Aversal	0,42	0,18	Aversal	-0,22	0,05	Aversal	0,11	0,01	Aversal	0,28	0,08	Aversal	0,34	0,12
Infl	-0,39	0,16	Infl	-0,22	0,05	Infl	0,79	0,63	Infl	-0,50	0,25	Infl	-0,28	0,08
Co2	0,11	0,01	Co2	0,02	0,01	Co2	0,73	0,54	Co2	0,29	0,09	Co2	0,52	0,28
Alc	-0,51	0,27	Alc	-0,08	0,01	Alc	0,91	0,83	Alc	0,26	0,07	Alc	0,80	0,64

North Africa: Algeria - 76,48
Egypt - 71,81
Libya - 71,12
Morocco -75,49
Sudan - 66,52
Tunisia - 76,71

West Africa: Benin - 60,96
Burkina Faso - 61,29
Gambia - 66,06
Ghana - 65,7
Guinea - 60,9
Guinea-Bissau - 64,25
Ivory Coast - 62,11
Liberia - 62,32
Mali - 60,67
Mauritania - 68,71
Niger - 61,43
Nigeria - 54,63
Senegal - 68,92
Sierra Leone - 61,96
Togo - 62,93
Burkina Faso - 61,29
Gambia -66,06
Ghana - 65,7
Guinea - 60,9
Guinea-Bissau - 64,25
Ivory Coast - 62,11

Central Africa: Cameroon - 63,97
Central African Republic - 57,67
Chad - 55,24
Equatorial Guinea - 63,91
Gabon - 68,51

East Africa: Burundi - 63,82
Comoros - 67,02
Djibouti - 66,2
Eritrea - 68,89
Ethiopia - 67,6
Kenya - 63,83
Madagascar - 63,83
Malawi - 67,56
Mauritius - 75,1
Mozambique - 63,8
Rwanda - 68,02
Seychelles - 72,99
Somalia - 58,97
South Sudan - 57,74
Tanzania - 67,21
Uganda - 68,49
Zambia - 66,53
Zimbabwe - 63,06

South Africa: Botswana - 69,29
Eswatini - 64,26
Lesotho - 57,8
Namibia - 67,52
South Africa - 66,31

4. Results and Discussion

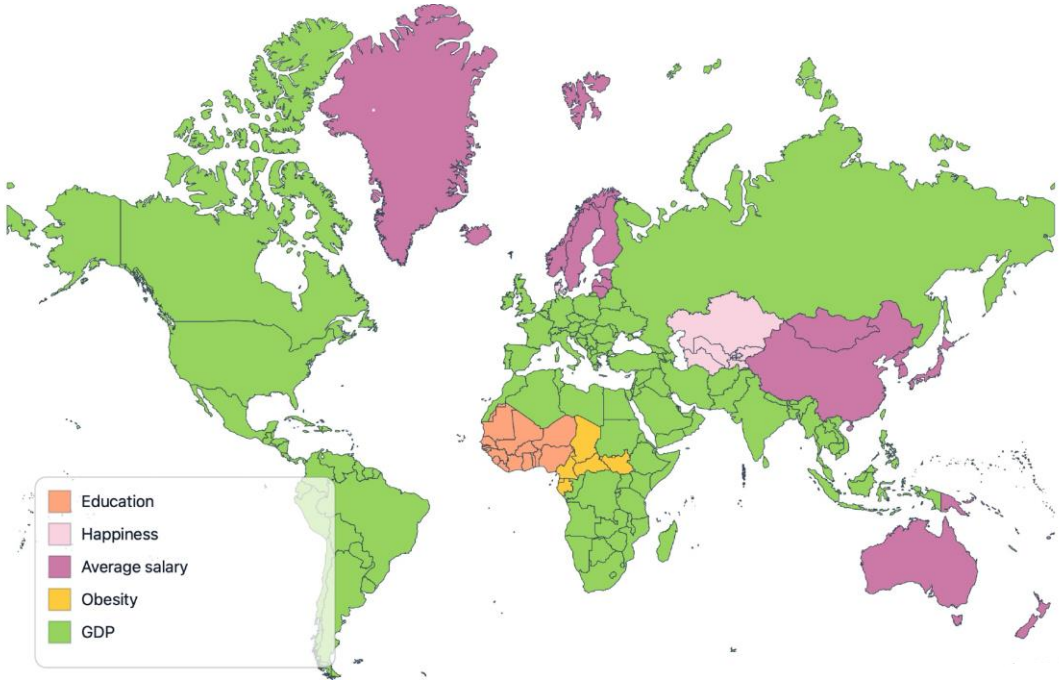

Figure 1. The factors that have the greatest positive impact on life expectancy Worldwide

As figure 1 illustrates, GDP has the most greatest positive impact worldwide. Here in most Asian and North American countries, life expectancy depends on it. The next factors that also have a great impact is the average salary, which can be seen in North Europe and some East Asian countries, and the education index, which can be seen in West Africa.

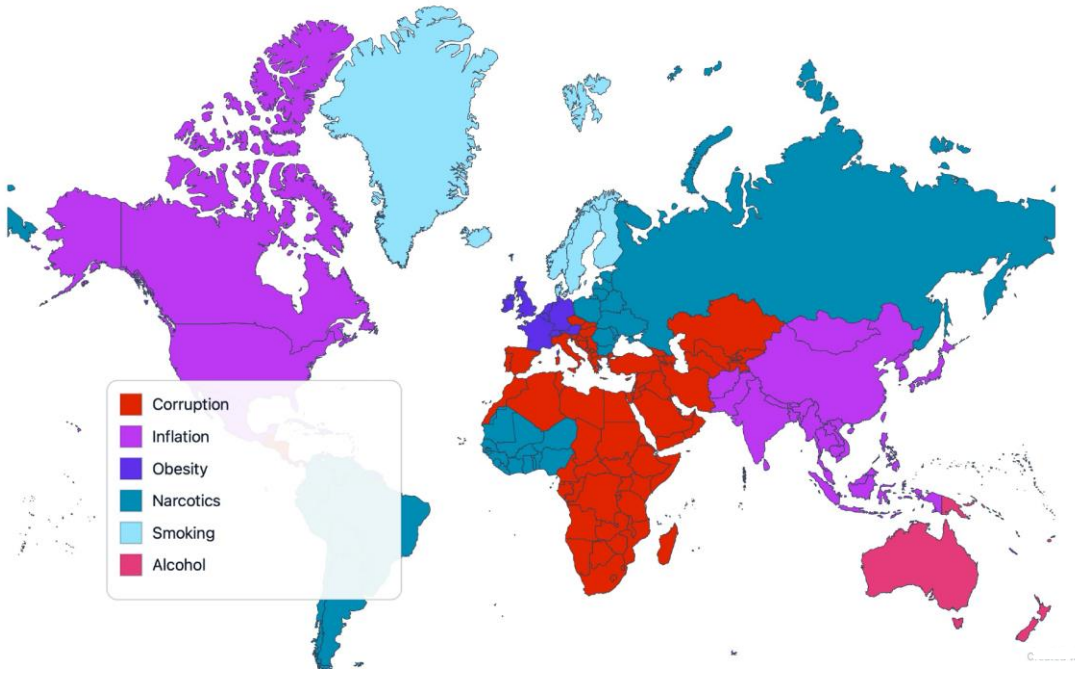

Figure 2. The factors that have the most negative impact on life expectancy Worldwide

In figure 2 it shows that factor which has the most negative impact on life

expectancy is inflation. In all countries of North America, South and East Asia, this factor is negative which affects the reduction of their life expectancy. The second most negative factor that affects life expectancy is corruption and the rarest one is obesity. Obesity only influences West Europe as an adverse cause.

Conclusion

A multiple regression model was used to evaluate the factors affecting life expectancy in World countries. To find out the relationship between life expectancy and socio-economic factors, correlation coefficients for different countries and continents were calculated by selecting several indicators. Factors with the lowest coefficients such as population size and area of countries were excluded. Overall, the results of this study con-

firm that life expectancy depends primarily on the overall state of a country's healthcare system, particularly on its level of economic development, social security, and the quality of governance. In Asia and North America, a high GDP has a more significant positive impact.

The negative impact of factors such as inflation and corruption is manifested in different ways in different regions of the world. For example, in North America, South Asia, and Eastern Europe, high inflation reduces economic stability and limits opportunities for health and social programs. Additional factors such as population size, employment rate, access to educational institutions and market infrastructure have a moderate positive impact in all regions, confirming the complex nature of the life expectancy formation process

Using a life expectancy model, it is possible to predict the implications of various changes in life expectancy for Kazakhstan and the world as a whole.

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PEDAGOGICAL SCIENCES

EXPERIMENTAL RESULTS OF THE EFFECTIVENESS OF AN ELECTRONIC TRAINER IN PREPARING STUDENTS OF THE 6B01509 "CHEMISTRY-BIOLOGY" EDUCATIONAL PROGRAM FOR THE TEACHER KNOWLEDGE ASSESSMENT

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«ХИМИЯ-БИОЛОГИЯ» БІЛІМ БЕРУ БАҒДАРЛАМАСЫ СТУДЕНТТЕРІН ПЕДАГОГТАРДЫҢ БІЛІМІН БАҒАЛАУҒА ДАЯРЛАУДА ЭЛЕКТРОНДЫҚ ТРЕНАЖЕР ТИІМДІЛІГІНІҢ ЭКСПЕРИМЕНТТІК НӘТИЖЕЛЕРІ

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Abstract

Currently, improving the professional training of teaching staff and preparing them for the system of assessing their knowledge is one of the pressing issues. In this regard, there is an increasing need to train future teachers using modern digital resources in higher education institutions. The purpose of the research work is to experimentally determine the effectiveness of an electronic simulator designed to prepare students of the 6B01509 “Chemistry-Biology” educational program for the procedure for assessing teachers’ knowledge.

Shakarim University in Semey was taken as the research base. About 70 students studying in the 3rd–4th year of the chemistry-biology specialty participated in the experiment. The research was conducted for 3 months. A special web platform https://tandau.online/ was developed, and a test database consisting of 500 questions in chemistry and 500 questions in biology was introduced into it. All tasks consisted of four answer options, one of which was marked as the correct answer. The testing time was 90 minutes, the total number of questions was 50, and the maximum result was 50 points.

As a result of the experiment, the initial diagnostic indicators of students ranged from 15 to 20 points, while at the final stage the majority achieved results of 25 to 35 points, and individual students showed 40 to 45 points. This showed that the systematic use of electronic simulators has a positive effect on improving the quality of education, consolidating subject knowledge, and psychological adaptation to testing.

The results of the study prove the effectiveness of introducing electronic simulators into the training system for future teachers.

Аңдатпа

Қазіргі таңда педагог кадрлардың кәсіби даярлығын жетілдіру және олардың білімін бағалау жүйесіне сапалы дайындау өзекті мәселелердің бірі болып табылады. Осыған байланысты жоғары оқу орындарында болашақ мұғалімдерді заманауи цифрлық ресурстар арқылы даярлау қажеттілігі артып отыр. Зерттеу жұмысының мақсаты – 6B01509 «Химия-Биология» білім беру бағдарламасы студенттерін педагогтардың білімін бағалау рәсіміне даярлауға арналған электрондық тренажердың тиімділігін эксперименттік тұрғыда анықтау.

Зерттеу базасы ретінде Семей қаласындағы Шәкәрім университеті алынды. Экспериментке химия-биология мамандығының 3–4 курсында білім алатын шамамен 70 студент қатысты. Зерттеу 3 ай көлемінде жүргізілді. Арнайы https://tandau.online/ веб-платформасы әзірленіп, оған химия пәнінен 500, биология пәнінен 500 сұрақтан тұратын тест базасы енгізілді. Барлық тапсырмалар төрт жауап нұсқасынан құралды, оның біреуі дұрыс жауап ретінде белгіленді. Тестілеу уақыты 90 минут, жалпы саны 50 сұрақ және ең жоғары нәтиже 50 балл болды.

Эксперимент нәтижесінде студенттердің бастапқы диагностикалық көрсеткіштері 15–20 балл аралығында болса, қорытынды кезеңде негізгі бөлігі 25–35 балл нәтижеге жетті, ал жекелеген студенттер 40–45 балл көрсетті. Бұл электрондық тренажерды жүйелі қолдану білім сапасын арттыруға, пәндік білімді бекітуге және тестілеуге психологиялық бейімделуге оң әсер ететінін көрсетті.

Зерттеу нәтижелері электрондық тренажерларды болашақ педагогтарды даярлау жүйесіне енгізудің тиімділігін дәлелдейді.

Keywords: teacher knowledge assessment, electronic trainer, assessment literacy, chemistry-biology education, formative assessment, retrieval practice, simulation-based learning

Кілт сөздер: педагогтердің білімін бағалау, электрондық тренажер, бағалау сауаттылығы, химия-биология мұғалімдерін даярлау, қалыптастырушы бағалау, retrieval practice, simulation-based learning

Жоғары педагогикалық білім беру жүйесіндегі өзекті міндеттердің бірі – болашақ мұғалімдерді кәсіби бағалау қызметіне мақсатты түрде даярлау. Қазақстанда педагогтердің білімін бағалау білім беру саласындағы уәкілетті орган әзірлеген тесттер арқылы педагогтің кәсіби құзыреттілік деңгейін айқындайтын рәсім ретінде сипатталады, ал оның нәтижесі бір жылға жарамды [1]. Бұл рәсім қазіргі уақытта жұмыс істеп жүрген педагогтерге ғана емес, педагогикалық өтілі жоқ және педагогикалық қызметті қайта бастауды жоспарлап отырған тұлғаларға да қатысты жүргізіледі [1]. Ұлттық тестілеу орталығының мәліметінше, 2024 жылы ПББ-ға қатысушылар саны 400 506 адамға жеткен [1]. Мұндай ауқым педагогикалық білім беру бағдарламаларында бағалау құзыреттерін алдын ала қалыптастыруды стратегиялық міндетке айналдырады.

6В01509 «Химия-Биология» білім беру бағдарламасы студенттері үшін бұл мәселе ерекше маңызды. Себебі болашақ химия және биология мұғалімі тек пәндік мазмұнды меңгеріп қана қоймай, оқу мақсаттарын нақтылау, дескриптор құрастыру, зертханалық және практикалық жұмыстарды әділ бағалау, білім алушылардың қателерін талдау, нәтижелерді түсіндіру және түзету жұмысына кері байланыс беру сияқты күрделі бағалау әрекеттерін орындай алуы тиіс. Критериалды бағалау қазіргі педагогикадағы ашықтық, объективтілік және өлшенетін нәтижеге бағдарлану қағидаттарымен тығыз байланысты [2, 98–100-бб.]. Ал қалыптастырушы бағалау күнделікті оқу үдерісінде білім алушының алға жылжуын бақылауға, оқыту мазмұнын дер кезінде түзетуге және оқу мотивациясын арттыруға мүмкіндік береді [3, 319–321-бб.].

Осыған байланысты болашақ мұғалімнің assessment literacy, яғни бағалау сауаттылығы ұғымы ерекше мәнге ие. Ғылыми әдебиеттерде бағалау сауаттылығы мұғалімнің бағалау құралдарын түсінуі, оларды оқу мақсаттарымен сәйкестендіруі, алынған деректерді интерпретациялауы және сол деректер негізінде оқытуды жетілдіре алуы ретінде қарастырылады [4, 251–252-бб.]. D. Rogier бағалау сауаттылығын тек тест құрастыру шеберлігімен шектемей, оқыту, кері байланыс және шешім қабылдау мәдениетімен байланыстырады [5, 3–4-бб.]. Демек, студенттерді ПББ-ға немесе жалпы бағалау қызметіне даярлау тек жекелеген сұрақтарды жаттатумен емес, кешенді бағалау ойлауын қалыптастырумен байланысты болуы керек.

Цифрлық білім беру ортасының дамуы бұл міндетті жаңа деңгейге шығарды. Organisation for Economic Co-operation and Development (OECD) материалдарында жоғары білімді цифрландыру мұғалімнің кәсіби құзыреттерін, соның ішінде Assessment бағытын, жаңа технологиялық шешімдер арқылы дамыту қажеттігін айқындайды [6, 11-б.]. Сонымен қатар мұғалімдерді цифрлық білім беру жағдайына даярлау жөніндегі OECD талдауы педагогтердің едәуір бөлігі бастапқы кәсіби даярлық кезінде ақпараттық-коммуникациялық технологияларды оқыту мен бағалауда жүйелі пайдалануға жеткілікті түрде үйретілмегенін көрсетеді [7, 9–10-бб.]. Осыдан келіп, педагогикалық жоғары оқу орнында электрондық тренажер, цифрлық кейс және жедел кері байланыс құралдарын қолдану ғылыми және практикалық тұрғыдан орынды болып көрінеді.

Электрондық тренажердің тиімділігін негіздеуде retrieval practice және simulation-based learning тұжырымдамалары да маңызды рөл атқарады. Зерттеулер практика тестілері материалды қайта оқумен салыстырғанда оқу нәтижесін анағұрлым жақсартатынын дәлелдейді [8, 659–660-бб.]. Retrieval practice бойынша кейінгі метаталдаулар тестілеу арқылы алынған білімнің жаңа жағдаяттарға тасымалдануына да оң әсер ететінін көрсетті [9, 710–712-бб.]. Мектептер мен аудитория жағдайындағы жүйелі шолу да retrieval practice-тің тұрақты түрде оқу жетістігін арттыратынын айқындады [10, 1410–1412-бб.], ал сыныптық quizzing-ке арналған метаталдау оның орташа деңгейдегі елеулі әсерін анықтады [11, 404–405-бб.]. Бұған қоса, мұғалімдерді даярлауда қолданылатын video-based simulations бағалау дағдыларын жетілдіруге және шынайы педагогикалық жағдаяттарды қауіпсіз ортада талдауға мүмкіндік береді [12, 2–3-бб.].

Зерттеу материалдары мен әдістері

Зерттеу Семей қаласындағы Шәкәрім университетінде жүргізілді. Экспериментке 6В01509 «Химия-Биология» білім беру бағдарламасының 3 және 4 курс студенттері қатысты. Жалпы қатысушылар саны шамамен 100 студентті құрады.

Эксперимент ұзақтығы – 3 ай. Зерттеу барысында студенттерге еркін режимде пайдалануға арналған арнайы **https://tandau.online/** электрондық платформасы ұсынылды.

Платформа мазмұны төмендегідей құрылымдалды:

- химия пәні бойынша – 500 сұрақ;
- биология пәні бойынша – 500 сұрақ;
- жалпы сұрақ саны – 1000;
- әр тапсырмада 4 жауап нұсқасы;
- бір ғана дұрыс жауап;
- тест ұзақтығы – 90 минут;
- жалпы тапсырма саны – 50 сұрақ;
- ең жоғары балл – 50.

Химия пәні бойынша мазмұн Ұлттық тестілеу орталығы бекіткен 20 тақырып негізінде 5 модульге бөлінді. Әр модульге 4 тақырыптан енгізілді. Биология пәні бойынша 13 тақырып 5 модульге

жіктелді. Модульдеу барысында 7–11 сынып мектеп бағдарламасындағы тақырыптар саны негізге алынды.

Электрондық тренажер құрылымы

Тренажер студенттердің өз бетінше дайындалуына ыңғайлы веб-ресурс ретінде әзірленді. Платформаның негізгі мүмкіндіктері:

- кез келген уақытта тест тапсыру;
- пән бойынша жеке таңдау жасау;
- уақытпен жұмыс істеуге дағдылану;
- нәтижені бірден көру;
- қателермен жұмыс жасау;
- қайталап тапсыру арқылы білімді бекіту.

Бұл жүйе студенттердің өзіндік жауапкершілігін арттырып, тұрақты дайындық дағдысын қалыптастырды.

Зерттеу әдістері ретінде бақылау, тестілеу, салыстырмалы талдау және сандық өңдеу қолданылды.

Электрондық тренажердің мазмұны химия және биология пәндерінің ерекшеліктерін ескере отырып құрастырылды. Тапсырмалар қорына оқу мақсаттарын оқу бағдарламасымен сәйкестендіру негізінде құрастырылды. Тренажер автоматтандырылған кері байланыс, дұрыс/қате жауап профилі, қателер картасы және әрекет бойынша қысқа әдістемелік түсіндірме беру функцияларымен толықтырылды.

Зерттеудің ғылыми жаңалығы мынадан көрінеді: біріншіден, болашақ химия-биология мұғалімдерін педагогтердің білімін бағалауға даярлауға арналған электрондық тренажердің құрылымдық моделі ұсынылды; екіншіден, студенттердің даярлығын сипаттайтын интегралды көрсеткіштер жүйесі нақтыланды; үшіншіден, электрондық тренажерді қолданудың нәтижелілігін көрсету үшін эксперименттік бағалау логикасы жасалды.

Эксперимент нәтижелері

Зерттеудің бастапқы кезеңінде студенттердің басым бөлігі 50 мүмкін балдың ішінде 15–20 балл аралығында нәтиже көрсетті. Бұл олардың пәндік білімін жүйелеу және тест форматына бейімделу қажеттілігін көрсетті. Студенттер тренажер негізінде өздерінің қандай тақырыптардан қиналатындығын біліп, ары қарай дайындық жасап, тестілеу нәтижелері айтарлықтай өсті.

Кесте – 1

Электрондық тренажер тиімділігінің үлгілік эксперименттік көрсеткіштері

Кезең	Нәтиже көрсеткіші
Бастапқы диагностика	15–20 балл
Қорытынды кезең	25–35 балл
Жоғары нәтиже көрсеткендер	40–45 балл

Алынған мәліметтер электрондық тренажер қолданудың оң әсерін дәлелдейді. Студенттердің көпшілігінде нәтижелердің 10–15 баллға жоғарылауы байқалды.

Талқылау

Зерттеу нәтижелері цифрлық платформаларды оқу процесіне енгізу студенттердің пәндік даярлығын арттыратынын көрсетті. Электрондық тренажердың басты артықшылығы – студенттердің өз қарқынымен дайындалуына мүмкіндік беруі.

Химия және биология пәндеріндегі теориялық материалдың көлемділігіне байланысты сұрақтарды модульдік жүйеде ұсыну мазмұнды жүйелі меңгеруге жағдай жасады. Сонымен қатар уақытпен тест орындау студенттердің емтихан жағдайына психологиялық бейімделуін күшейтті.

Зерттеу нәтижелері болашақ педагогтерді даярлауда цифрлық құралдардың тиімділігін көрсететін заманауи еңбектермен үндеседі.

Қорытынды

Жүргізілген эксперимент нәтижесінде 6В01509 «Химия-Биология» білім беру бағдарламасы студенттерін педагогтардың білімін бағалау рәсіміне даярлауда электрондық тренажердың тиімділігі дәлелденді.

https://tandau.online/ платформасын пайдалану нәтижесінде студенттердің тест көрсеткіштері айтарлықтай жақсарды: бастапқы 15–20 баллдан 25–35 баллға дейін өсті, ал жекелеген білім алушылар 40–45 балл нәтижеге жетті.

Электрондық тренажер студенттердің өзіндік жұмысын ұйымдастыруға, білімді жүйелеуге, тест форматына бейімделуге және кәсіби даярлығын арттыруға мүмкіндік береді.

Осыған байланысты жоғары оқу орындарында болашақ педагогтерді даярлау жүйесіне осындай цифрлық ресурстарды енгізу тиімді деп есептеледі.

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RETHINKING THE FUTURE OF EDUCATION: INNOVATIONS IN MODERN TEACHING COMPETENCIES

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Abstract

One of the most distinctive features of the modern world is the rapid pace of change occurring across nearly all spheres of life. These transformations profoundly affect both individual and social existence, and social institutions are not exempt from this process. Educational institutions, in particular, emerge as some of the most responsive and adaptable structures in the face of such change. Naturally, various factors make this transformation inevitable. This theoretical study analyzes the relationship between the evolving nature of the teaching profession and the dynamics of a rapidly changing world, while also presenting theoretical propositions regarding the future of teaching. The study argues that factors such as technological advancement, increased investment in education, social transformation, shifting societal demands, the growing influence of parents, rising student numbers, the role of mass media, and the demand for quality education make change within the teaching profession unavoidable. However, the drivers of change are not limited to these factors; several additional elements further accelerate this process. Some studies associate the extensive application of educational technologies with the potential disappearance of the teaching profession in the future. In contrast, other research emphasizes that, since human beings are inherently emotional and social, an education system without teachers is unlikely to emerge. In this regard, the teacher remains not merely a transmitter of knowledge, but a central figure addressing learners' psychosocial needs. The study concludes that the teaching profession will not vanish in the foreseeable future; rather, the role and status of teachers will undergo transformation. The teacher of the future will be a multifaceted individual—technologically literate, adaptive, and equipped with strong interpersonal and social skills.

Keywords: teaching profession, future of education, future teacher

Introduction

No society is stagnant or static; every society experiences continuous dynamism and transformation. However, social change does not always manifest in a clear or consistent manner, nor does it proceed at a uniform pace. At the core of these changes lies the individual—both as an agent influencing change and as one influenced by it. Innovation, encompassing the emergence of new ideas and methods, not only challenges the past but also shapes the trajectory of a society's future.

In this regard, education plays two fundamental roles with respect to innovation: first, to equip society with qualified professionals capable of meeting modern and innovative demands; and second, to facilitate these changes with minimal social resistance or "friction." Within this framework, as with all professions, numerous questions arise concerning the future of teaching. What awaits the teaching profession in the coming years? Will its social prestige and functional significance increase, decrease, or undergo complete transformation? Could teaching itself be redefined or even rendered obsolete?

It is important to note, however, that it is impossible to predict with absolute certainty what the teaching profession will look like in ten or twenty years. As Yaşaroğlu (2018, p. 17) aptly observes, "no one possesses a crystal ball" to foresee such developments.

Education, often characterized as an open system, is understood as a process of stimulating continuous and purposeful change in learners' behavior. In this sense, universities, as centers of educational activity, must aim not only to impart knowledge but also to prepare students for real-life challenges after graduation (Jukes, McCain & Crockett, 2010, pp. 19–20). During periods of profound transformation, societies may experience what can be termed "paradigm paralysis"—a form of conceptual stagnation in the face of future-oriented challenges. Such situations may necessitate abandoning previously accepted ideas and values in light of new realities. Therefore, when developing strategies and goals for the future of education, this reality must be acknowledged.

It should also be noted that ongoing and dynamic changes affect not only technology and the economy but also all social systems—particularly education. These influences encompass a wide spectrum, ranging from the content of education to its organizational structures, pedagogical approaches, and teacher–student relationships.

The present era is characterized by rapid change, intensifying competition, and the pervasive influence of globalization across all domains. Under such conditions, opportunities and risks alike have increased significantly for individuals, institutions, and nations. Importantly, these changes are neither random nor accidental; their underlying causes can be summarized as follows:

Factors Driving Change In Education And The Transformation Of The Teaching Profession

1.Rapid Advances in Science and Technology

2.Acquisition, Utilization, Analysis, and Development of Information

3.Emergence of New Problems and Needs Confronting Humanity

4.The Individual's Drive for Self-Realization and the Associated Demands

These factors represent the primary drivers of change and exert a significant influence on nearly every dimension of future life. In the contemporary era, remarkable progress has been achieved in the field of information and communication technologies—particularly in the collection, processing, transmission, and application of information, as well as in the production of new knowledge. This technological transformation has led to profound changes both in educational curricula and in societal expectations regarding the outcomes of education. The challenges brought about by such change necessitate the evolution and transformation of the teacher factor—the most dynamic and adaptable component of the educational system.

In this context, teachers assume a crucial role in the implementation of renewed educational programs and in the cultivation of students who are engaged, creative, innovative, and capable of working collaboratively. The organization of future teaching and learning processes will, to a considerable extent, depend on educational policies developed at the individual and collective levels. Despite the emergence of technologies whose full potential is not yet realized, the fundamental nature of instruction—defined by the values, knowledge, competencies, responsibilities, and goals of those who teach—must remain central.

Rapid technological progress continues to influence education profoundly. The integration of technology into teaching—exemplified by the use of robots and artificial intelligence–based systems in universities—indicates that both the structure of instruction and the very essence of the teaching profession are subject to transformation. Such innovations may necessitate the redefinition of traditional teacher roles and require educators to adapt to new positions that involve collaboration with technology. Consequently, the future of education will depend not only on technological advancements but also on how and for what purposes these technologies are integrated into learning environments—and, most importantly, on the attitudes and adaptive capacities of teachers toward such change.

Although a number of reforms have been implemented in Azerbaijan's teacher education system, many educators continue to rely on traditional instructional methods characteristic of previous eras. Despite the modernization of university infrastructure and the introduction of advanced technologies, the persistence of outdated teaching approaches remains a significant challenge. Expecting different outcomes from students without corresponding transformations in teachers' pedagogical practices appears unrealistic. In this regard, Harwell's (2003) oft-cited assertion aptly captures the situation: "If you always do what you've always done, you will always get what you've always gotten." This statement underscores the importance of teachers' critical reflection on their own practice and their openness to pedagogical change. If the anticipated transformations within the education system are to be realized, and if students are to be equipped to meet the demands of a new era, such change must begin with teachers themselves.

Purpose and Methodological Approach of the Study

The primary objective of this study is to project possible directions for the future development of the educational environment and to forecast the nature of anticipated transformations within the teaching profession. To this end, the study analyzes existing scholarly approaches and practical initiatives concerning the overall future of education, with a specific focus on the evolution of teaching as a profession. Drawing on current literature, potential future scenarios are systematized, classified, and discussed within an academic framework. Within this scope, examples of technological integration into contemporary educational settings are examined alongside an in-depth analysis of the concept of "change" and the principal factors necessitating such transformations.

Reasons Necessitating Change

As in all professional fields, transformation within the teaching profession has become inevitable due to a combination of objective and subjective factors. The principal forces driving change in modern teaching can be summarized as follows:

1.Social Transformations and Societal Expectations of Teachers

Rapid and multifaceted social transformations have made it necessary to reconsider the roles of educational institutions, educational systems, and teachers in particular. Compared to two decades ago, education has evolved into a far more complex and multidimensional process. This complexity demands not only the transformation of teaching methodologies but also the redefinition of teachers' functional roles. Contemporary society no longer perceives teachers solely as transmitters of knowledge; rather, they are viewed as key figures in shaping students' social, emotional, technological, and civic competencies. Consequently, teachers are required to adapt their traditional roles to the expectations of an evolving society.

One of the most significant social developments affecting education is the growing involvement and assertiveness of parents. Parents today seek not only to ensure that their children's current educational needs are met but also that they are prepared to face the challenges of the future. This expectation has a direct impact on teachers' professional preparation, their pedagogical approaches, and their engagement with the educational process. Collectively, these dynamics indicate that social change will continue to bring about profound transformations in teachers' roles and functions. As a result, teaching is progressively becoming a more flexible, multifaceted, technologically enriched, and socially oriented profession.

2.Parental Influence and the Expanding Social Role of the Teacher

In recent years, there has been a notable increase in the number of working parents. At the same time, higher divorce rates and the decreasing amount of time parents spend with their children have, in many cases, negatively affected children's emotional and social development. Consequently, some of the traditional functions of the family in child upbringing have shifted toward teachers. In today's context, many of the values, social norms, and emotional support mechanisms once transmitted within the family are now being provided within educational institutions—primarily by teachers.

As a result, parental expectations increasingly rest on the assumption that nearly all aspects of their children's development should be addressed within the school environment. This, in turn, is often linked to the limited time and attention parents can devote to learning activities at home. Such circumstances can be interpreted as a partial transfer of parental responsibilities to teachers. Accordingly, teachers are no longer merely facilitators of academic learning but also play active roles in affective (emotional and social) education. This shift substantially expands teachers' professional workload and spheres of responsibility.

Hence, as the functional boundaries between the family and the educational institution become increasingly blurred, the teacher's role grows more multifaceted and complex. This situation calls for new approaches in teacher education—particularly those that emphasize the development of social and emotional competencies alongside professional and technological expertise.

3. Changes in the Student Model and the Role of the Teacher

In the contemporary educational process, the traditional student model has undergone a fundamental transformation. Students are no longer perceived as passive recipients of information but as active participants who construct their own learning experiences. In modern classrooms, students engage in discussions, group work, and diverse learning activities rather than merely listening to lectures. This shift has profoundly affected the teacher's role, transforming teachers from transmitters of knowledge into facilitators of learning—organizers and enablers of the educational process (Çakmak, 2011). Education today is therefore understood not as a simple transmission of information but as a comprehensive system aimed at promoting students' multidimensional development.

Moreover, teachers are now expected to support students' healthy and balanced development and to engage meaningfully in their lives. Students increasingly face physical and emotional violence, neglect, and a variety of personal and social problems, and teachers play a vital role in addressing these challenges (Deiro, 2005). In this sense, the teacher's role extends beyond pedagogy to encompass social and emotional support functions. Consequently, in modern educational contexts, teacher–student interaction must adapt to new dynamics, with the learning process directed toward the simultaneous development of academic and social competencies.

Integration of Technology into the Education and Learning System

Mass media have significantly expanded access to information, allowing students to recognize the importance of using diverse informational resources, including those employed by their teachers. The continuous influx of new digital media tools into the educational environment accelerates this transformation. Teachers who rely solely on verbal instruction are increasingly perceived as ineffective. Instead, educators can enhance student motivation by presenting content in engaging and interactive ways through the effective use of powerful information resources. In this context, the need for a "digital revolution" in the education system becomes evident.

The teaching profession, accordingly, must evolve through the digital learning revolution into a domain that enables exceptional educators to reach larger audiences and in which their expertise is both recognized and rewarded (Hassel & Hassel, 2011). Among the various forces driving educational change, technological advancement and its integration into learning processes are among the most significant. Some researchers predict that in the near future, robots and biotechnological education will become realities, arguing that technological progress could transform all sciences and reshape our understanding of human and natural structures. The increased use of technology in education will likely alter both the teacher's role and the very concept of education itself.

However, these transformations are not without potential drawbacks. Several scholars caution that technological systems operating beyond human oversight could give rise to artificial entities, thus introducing potential risks and ethical dilemmas into every scientific and educational advancement (Sönmez, 2002, p. 320).

Sharkey (2016) proposes four possible scenarios for the use of technology in future classroom environments:

1.Robot Teachers: The teacher figure in the classroom is replaced by a robotic entity that serves as the main source of information and manages the instructional process.

2.Robots as Peers and Companions: Robots act as learning partners or classmates, facilitating interaction and engagement.

3.Robots as Caregivers and Assistants: In these cases—collectively referred to as support robots—the robotic systems do not replace human teachers but serve as aids that simplify instructional tasks. They do not occupy positions of authority but operate in supportive roles.

4.Telepresence Robots: These robots enable remote instruction, allowing human teachers to conduct lessons in real time without being physically present in the classroom.

In our view, the primary objective of most robotics researchers is not to replace teachers entirely but to enhance the educational experience by positioning robots as stimulating and engaging tools that add value to the learning process. For successful integration of robots into classrooms, human teachers must be able to operate these technologies with ease. This, in turn, requires

the development of appropriate interface mechanisms—software systems, technical devices, or mobile applications—that allow teachers to manage robots with minimal training (Ahmad & Mubin, n.d.).

The process of digitalization in education is not new; it has been underway for decades. One of the earliest examples of technology integration in education was Apple's "Apple Classrooms of Tomorrow (ACOT)" project in the 1980s. In the 2000s, the "Preparing Tomorrow's Teachers to Use Technology" initiative represented another significant milestone in this direction (Pamuk, Çakır, Ergün, Yılmaz & Ayas, 2013). Today, a wide variety of educational robots are available, ranging from simple microprocessor-based mobile units to complex humanoid systems. The choice of robot type depends largely on the learning objectives, the educational field, and the students' age group. Small-scale robots are typically used in robotics and computer science education, while humanoid robots—due to their natural and engaging communicative abilities—are often employed in language learning contexts (Ahmad & Mubin, n.d.).

Disadvantages of Technology Use in Universities

Although technologies used in university environments offer numerous advantages, they also raise concerns. For example, robotic instructors can engage with large numbers of students simultaneously and offer "unlimited" learning opportunities through video-based instruction. Furthermore, intelligent software that personalizes learning experiences increases student engagement and facilitates individualized learning environments (Hassel & Hassel, 2011). Research also shows that students enjoy interacting with robots in educational settings, and such interactions significantly enhance their motivation to learn (Ahmad & Mubin, n.d.). Empirical findings indicate that information taught by robots was retained 27% more effectively compared to content that was not robot-mediated. Based on such results, researchers argue that robots can serve as efficient and cost-effective tools for enriching the learning environment.

Nevertheless, public concern persists regarding the increasing use of high-tech tools—particularly robots—in university education. Studies reveal that public attitudes toward educational robots remain ambivalent. For instance, a 2012 survey conducted across Europe with over 27,000 respondents found that 34% of participants believed the use of robots in education should be prohibited, while 60% considered it inappropriate for robots to care for children, the elderly, or people with disabilities. Only 3% regarded the use of robots in education as desirable (Sharkey, 2016). These results suggest that the integration of robots into educational environments has yet to gain full public trust and acceptance.

As previously noted, the rapid emergence of digital learning has given rise to predictable debates within the field of education. Teachers' unions and their representatives have voiced the argument that "a teacher cannot be replaced by a laptop" (Hassel & Hassel, 2011), expressing concerns over the potential of technology—including online learning, digital course programs, video lectures, and other technology-based instructional methods—to supplant human educators. From the teachers' perspective, the integration of robotics and other technological tools into the teaching process presents certain challenges and difficulties.

First, robotics-based instruction requires considerable time, both during class (for construction, design, and testing stages) and outside of class (for lesson planning, gathering materials, troubleshooting, and preparation). Moreover, factors such as the high cost of materials, limited classroom space, and short lesson durations create restrictive conditions even for the most motivated and innovation-oriented teachers (Cejka, Rogers, & Portsmore, 2006). Consequently, teachers often prefer to maintain full control over the use of robots, expressing skepticism toward the technical reliability of these systems and favoring their use as assistive tools or companions that support student learning rather than as replacements for human instructors.

The support and endorsement of educational administrators also play a crucial role in shaping attitudes toward robotics in the classroom. Research indicates that teachers may experience fatigue and obstacles when attempting to introduce robotics into their classrooms without institutional backing (Cejka et al., 2006). Therefore, administrative support can serve as an important mechanism for alleviating teacher concerns and facilitating the adoption of innovative technologies.

Ethical concerns surrounding the use of robots in education have also been raised. Questions related to transparency in monitoring robot performance and accountability for errors remain unresolved. The use of robots in contexts involving vulnerable populations—such as children or the elderly—raises significant issues of oversight and responsibility.

As products of artificial intelligence, robots enable the creation of artificial environments within the teaching process. However, research shows that many students perceive robotic voices as unnatural and experience difficulty adapting to such environments. The integration of robots into education also entails privacy-related risks. Previous discussions have questioned the potential intrusion of robots into individuals' private lives. The collection of personal data through robotic sensors may compromise privacy: information gathered—even from a single monitored individual—can be transmitted to human monitors or stored in the robot itself for potential access by others (Ahmad & Mubin, n.d.).

Additionally, the implementation of robotics in education raises concerns about employment. Teachers and teachers' unions argue that widespread adoption of robots within education could threaten the job security of educators and other educational staff worldwide (Soffar, 2016). Another major concern relates to the possible reduction of human interaction resulting from the use of social robots. Critics argue that robotic teachers cannot replicate the creativity and innovation of human educators when delivering instructional material. The silicon-based brain of a robot, they contend, cannot match the productivity of the carbon-based human

brain and thus lacks the capacity to respond creatively to novel or ambiguous questions.

Furthermore, robots' evaluative and feedback functions are often deemed inadequate: they cannot provide meaningful positive reinforcement or constructive criticism, interpret student work effectively, or accommodate individual differences (Goldstein, 2013). It is also suggested that reliance on robots might hinder children's ability to develop personal responsibility. A lack of emotional connection or bonding between children and robots constitutes another potential disadvantage, as does the lower level of socialization observed in classrooms that utilize robots—factors that may impede the development of students' interpersonal skills.

From an economic standpoint, the integration of technology into educational environments is consistently associated with high costs. Robotic teachers, in particular, represent expensive technologies whose implementation may further exacerbate financial concerns within the education sector.

The Role of Universities in Shaping Future Teachers in Azerbaijan

In today's modern, globalized world, university education has become a critical component of each nation's socio-economic development, competitiveness, and sustainability. As a unique and essential element within the education system, universities contribute significantly to fostering innovation, human capital, and cultural development. It is therefore not coincidental that UNESCO has identified universities as indispensable institutions for supporting social progress, economic growth, the production of competitive goods and services, the preservation of cultural identity, social cohesion, poverty reduction, and the promotion of a culture of peace.

At present, university education is both a prerequisite for maintaining a strong position in the global knowledge economy and a key factor in ensuring individual and national competitiveness. It has also become a central component of economic operations and policymaking processes.

In general, improvements in the quantitative dimensions of education are expected to be accompanied by qualitative enhancements. However, while the number of teachers and students in universities has increased, this growth has not necessarily resulted in qualitative improvements. The expansion in quantity has, in fact, complicated the understanding and measurement of quality. This situation requires teachers to remain aware of the evolving nature of their professional roles, to adapt to new realities, to ensure continuity in instruction, and to strive for excellence across all domains of education.

In this regard, the "Future Education Leaders of the Pedagogical University" competition, successfully launched at the Azerbaijan State Pedagogical University in 2024, continued in 2025 as its second season. With the participation of 400 students, the competition was conducted in four stages.

•In the first stage, participants were assessed on their knowledge of Azerbaijan and the university, as well as their general worldview.

•The second stage evaluated logical reasoning, information processing, and analytical thinking skills.

•During the third (semifinal) and fourth (final) stages, participants demonstrated their abilities to work individually and in teams, employ strategic thinking, design and present projects, and exhibit public speaking, presentation, self-expression, and creativity skills.

The final round, held on May 9, 2025, identified ten students with the highest performance. Sponsored by bp Azerbaijan, the competition's primary objective was to support the professional development of talented students and to cultivate the future human resource potential of the university. Each winner received a ₼1000 monetary award, unique gifts, and the opportunity to participate in a year-long professional mentorship and development program.

Thus, in order to broaden the scope of prospective teachers' research competencies, a survey was conducted among first- and second-year students enrolled in the Primary School Teacher Education program (future primary school teachers). The results of this survey made it possible to draw several key conclusions.

First, the analysis of the findings revealed that student participation in research activities within universities remains quite limited. The instructional process largely retains an executive and reproductive character. The primary reason for this situation lies in students' tendency to prioritize rote learning over analytical or investigative engagement.

Second, among first-year students, performative approaches continue to outweigh innovative ones. Lecturers and instructors generally do not devote sufficient time during lectures and seminars to support the development of students' research skills. Consequently, the learning process is primarily confined to passive listening, reproductive explanation, memorization of lecture content, and similar activities. Finally, insufficient attention is paid to cultivating students' research abilities, and the independent assignments they are given are often implemented without clear methodological direction or qualitative intent.

Higher education institutions, while delivering state-mandated curricula and applying various instructional technologies, succeed in fostering certain professional skills among graduates. However, there is little evidence of systematic effort to prepare students for adaptability in dynamic contexts or to enable them to perform effectively in nontraditional situations. Moreover, the insufficient consideration of existing traditions and values within the process of teacher preparation represents an additional area of concern.

In our view, the shock caused by the pandemic—similar to developments in other sectors—is likely to deepen the divide between under-resourced and well-established higher education institutions. Its impact will likely compel universities and colleges to address long-overdue reforms, increase specialization, strengthen collaboration networks, and even merge with other institutions if unable to sustain independent operation. It appears that institutions that recognize the shortcomings revealed by this crisis, acknowledge the opportunities created by new realities, and implement

innovative solutions promptly will enter the "new normal" era from a stronger position.

Conclusion

Among the main factors shaping the educational environment are social changes, public expectations, parental influence, transformations in teaching models, the evolving concept of quality, and the integration of technology into the learning process. Under the influence of these factors, transformations in education are inevitable—and these changes will also reshape the role of teachers.

Research indicates that the use of robots in instruction increases students' motivation and engagement while expanding opportunities for individualized learning. Such advantages make the incorporation of technology into educational settings practically indispensable. Considering the trajectory of technological development, it is highly probable that the tools used in universities in the near future will be more advanced, functional, and comprehensive than those available today. Nevertheless, this does not preclude the use of robots at other educational levels. Depending on the lesson's objectives, artificial intelligence tools can also be successfully applied in various stages of education.

Scholars argue that this trend could fundamentally transform the role of teachers within the education system—an idea often summarized by the phrase "from the sage on the stage to the guide on the side." In other words, while the roles of educators in the future will differ from those of the past and present, their functions will not disappear entirely. Teachers of this new era will help students acquire the knowledge, skills, behaviors, and values necessary to become responsible parents, competent professionals, and productive citizens.

Accordingly, it can be projected that the teaching profession will not vanish but rather evolve in form and function. Just as today's teachers differ from those of the past, tomorrow's teachers will likewise differ from the educators of today.

At the same time, it must be acknowledged that the use of technology carries certain disadvantages. Based on this argument, the future direction and purpose of education must remain centered on the individual. Minimizing the potential negative effects of technological integration begins with effective and deliberate planning. Teachers must therefore adopt preventive strategies and safeguards to ensure that those they educate do not develop undesirable traits or dependencies.

From the conducted research, it can be concluded that, at least in the near future, teachers will continue to hold the most favorable position for cultivating students' higher-order thinking skills, analyzing complex problems, applying knowledge and competencies, comprehending abstract concepts, and generating innovative ideas and solutions.

Although technological progress has deeply affected not only individual lives but also interpersonal communication, social dynamics, and international relations, the human element will never lose its significance. Hence, while education must continually adapt to technological advancements, the complete removal of the human factor is neither possible nor desirable. This reality underscores that the teaching profession will continue to exist and maintain its vital role in the world of the future.

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PSYCHOLOGICAL SCIENCES

CREATIVITY AS A PHENOMENON: PSYCHOLOGICAL APPROACHES AND AN ANALYSIS OF WEISBERG'S THEORY

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Abstract

The psychology of creativity is one of the important branches of psychology that studies an individual's ability to generate new ideas, approach existing problems in unconventional ways, and produce original outcomes. In the modern era, creativity is no longer confined to the field of art; it also plays a crucial role in science, education, technology, and all aspects of everyday life. For this reason, the psychology of creativity has become a broad subject of investigation from both theoretical and practical perspectives. Creativity is one of the most complex and multifaceted forms of human activity.

This process is not limited to the generation of new ideas; it also encompasses the application and implementation of those ideas. The psychology of creativity examines various factors that influence creative performance, including individual characteristics, motivation, environmental conditions, and cognitive processes. The main aim of this article is to provide a comprehensive analysis of the nature of creativity, its major theoretical approaches, research methods, and practical significance.

Keywords: creativity, psychology, approach, ideas, methods, cognitive

Introduction - Creativity has long been regarded as one of the most complex and fascinating aspects of human cognition. It plays a central role in scientific discovery, artistic expression, technological advancement, and everyday problem-solving. Despite its significance, defining and explaining creativity has remained a challenge across disciplines such as psychology, education, and cognitive science. Traditionally, creativity was associated with exceptional individuals and mysterious processes of inspiration. However, contemporary psychological research increasingly conceptualizes creativity as a cognitive and developmental phenomenon grounded in ordinary mental processes.

This paper explores creativity as a psychological construct by examining major theoretical approaches and providing an in-depth analysis of the perspective proposed by Robert W. Weisberg. Weisberg's theory challenges traditional assumptions about creativity by emphasizing the role of normal cognitive processes, knowledge accumulation, and gradual development rather than sudden insight or innate genius. By integrating classical theories with Weisberg's framework, this article aims to provide a comprehensive and critical understanding of creativity as both a universal and learnable human capacity.

Creativity is commonly defined as the ability to produce ideas, solutions, or products that are both novel and valuable. This dual criterion originality and usefulness has become widely accepted in psychological literature. Creativity is not limited to artistic or scientific domains; it is also evident in everyday activities such as teaching, communication, and problem-solving.

From a psychological standpoint, creativity involves several cognitive processes, including divergent thinking, associative thinking, problem restructuring, and analogical reasoning. It also incorporates affective and motivational components such as curiosity, intrinsic motivation, and openness to experience. Therefore, creativity is best understood as a multidimensional construct that integrates cognitive, emotional, and environmental factors.

Major Psychological Approaches to Creativity:

1. Psychoanalytic Approach - The psychoanalytic perspective, rooted in the work of Sigmund Freud, views creativity as an expression of unconscious desires and internal conflicts. According to this view, creative activity allows individuals to channel repressed emotions into socially acceptable forms. Artistic and literary creativity, in particular, is often interpreted as symbolic expression. While this approach provides insight into the emotional and symbolic aspects of creativity, it has been criticized for its lack of empirical support and overemphasis on pathology. It tends to portray creativity as a byproduct of psychological tension rather than a constructive cognitive process.

2. Humanistic Approach - Humanistic psychologists such as Abraham Maslow and Carl Rogers emphasize creativity as a natural expression of self-actualization. According to this perspective, creativity emerges when individuals realize their full potential and experience psychological freedom. Maslow identified creativity as a characteristic of self-actualized individuals, while Rogers highlighted the importance of a supportive environment that fosters openness and intrinsic motivation. In this view, creativity is not limited to a select few but is a universal human potential. This approach has had a strong influence on educational practices, encouraging the development of learner-centered environments that promote exploration and self-expression.

3. Cognitive Approach - The cognitive approach focuses on the mental processes underlying creative thinking. Researchers in this tradition study how individuals generate, manipulate, and evaluate ideas.

- **Divergent thinking**: generating multiple possible solutions

- **Convergent thinking**: selecting the most appropriate solution

- **Problem restructuring**: redefining problems to find new solutions

- **Analogical reasoning**: applying knowledge from one domain to another

Cognitive theories emphasize that creativity is not a mysterious process but a set of identifiable and trainable skills. This perspective laid the groundwork for modern creativity research and assessment. The cognitive approach to creativity represents one of the most influential and empirically grounded perspectives in modern psychology. It conceptualizes creativity not as a mysterious or purely intuitive phenomenon, but as a set of mental processes that can be observed, analyzed, and developed. Researchers within this framework investigate how individuals generate ideas, transform knowledge, solve problems, and evaluate possible solutions. From this perspective, creativity is deeply embedded in everyday thinking and relies on general cognitive functions such as memory, attention, and reasoning.

At the core of the cognitive approach is the assumption that creative thinking involves both the generation of novel possibilities and the evaluation of their usefulness. These processes are typically described through several key components: divergent thinking, convergent thinking, problem restructuring, and analogical reasoning.

Divergent Thinking - Divergent thinking refers to the ability to generate multiple, varied, and original ideas in response to an open-ended problem. It is often considered a primary indicator of creative potential. This type of thinking is characterized by:

- Fluency (number of ideas produced)
- Flexibility (variety of idea categories)
- Originality (uniqueness of ideas)
- Elaboration (level of detail)

Convergent Thinking - Convergent thinking, in contrast, involves selecting the most appropriate, effective, or feasible solution from a set of alternatives. It requires logical reasoning, critical evaluation, and decision-making. While divergent thinking generates options, convergent thinking narrows them down.

Problem Restructuring - Problem restructuring involves redefining or reframing a problem in order to discover new and more effective solutions. Often, individuals fail to solve problems because they are constrained by initial assumptions or fixed perspectives. By changing how a problem is perceived, entirely new solution paths can emerge.

Analogical Reasoning - Analogical reasoning involves applying knowledge or solutions from one domain to another. It allows individuals to draw connections between seemingly unrelated concepts and transfer insights across contexts. This process is fundamental to many creative breakthroughs.

Cognitive Theories and the Nature of Creativity - Cognitive theories fundamentally challenge the idea that creativity is a rare or mysterious gift. Instead, they propose that creativity consists of identifiable, teachable, and improvable skills. These include:

- Generating multiple ideas (divergent thinking)
- Evaluating and selecting solutions (convergent thinking)
- Reframing problems (problem restructuring)
- Making connections across domains (analogical reasoning)

From this perspective, creativity is not limited to artists or geniuses; it is a universal human capacity that can be developed through practice, education, and experience. **Implications for Education and Practice -** The cognitive approach has had a profound impact on educational systems and professional practices. It suggests that creativity can be fostered by:

- Encouraging open-ended questions
- Promoting brainstorming activities
- Teaching problem-solving strategies
- Providing opportunities for interdisciplinary learning

A teacher might ask students to design a sustainable city. This task requires:

- Divergent thinking (generating ideas)
- Convergent thinking (choosing feasible solutions)
- Problem restructuring (rethinking urban challenges)
- Analogical reasoning (learning from existing cities or ecosystems)

The cognitive approach provides a comprehensive and practical framework for understanding creativity. By focusing on mental processes such as divergent and convergent thinking, problem restructuring, and analogical reasoning, it explains how creative ideas are generated and refined. Most importantly, it demonstrates that creativity is not an elusive or innate talent but a set of cognitive skills that can be systematically developed and applied across domains.

4. Sociocultural Approach - The sociocultural perspective highlights the role of environment, culture, and social interaction in creativity. Creativity is not seen as an isolated individual trait but as a product of interaction between individuals and their context.

Factors influencing creativity include:

- Educational systems
- Cultural values
- Social support
- Access to resources

This approach emphasizes that what is considered "creative" varies across cultures and historical periods. It also underscores the importance of collaboration and shared knowledge in creative production.

The Weisberg Perspective on Creativity - Robert W. Weisberg offers a distinctive and influential perspective on creativity, particularly through his work *Creativity: Understanding Innovation* (2006). Contrary to traditional views that associate creativity with sudden insight or exceptional talent, Weisberg argues that creativity arises from ordinary cognitive processes.

1. Creativity as Ordinary Thinking - One of Weisberg's central claims is that creativity does not require special mental mechanisms. Instead, it relies on

the same cognitive processes used in everyday thinking, such as memory retrieval, problem-solving, and logical reasoning [Runco, M. A, 2007].

According to this view:

- Creative individuals are not fundamentally different from others
- Creativity is accessible to everyone
- Differences in creative output are due to experience and effort rather than innate ability

This perspective democratizes creativity and challenges the myth of the "creative genius."

2. The Role of Knowledge - Weisberg emphasizes that creativity is deeply dependent on domain-specific knowledge. Individuals who possess extensive knowledge in a particular field are more likely to generate innovative ideas because they can: [Weisberg, R. W, 2006]

- Recognize patterns and gaps
- Combine existing concepts in novel ways
- Build upon prior work effectively

This idea contradicts the belief that creativity requires "thinking outside the box" in the sense of ignoring existing knowledge. Instead, Weisberg argues that the "box" itself knowledge is essential for creativity.

3. Incremental Development - Another key element of Weisberg's theory is the notion that creativity develops gradually rather than through sudden breakthroughs. He critiques the concept of "insight" as an instantaneous and mysterious process, suggesting that it is often the result of continuous effort and gradual refinement.

Creative achievements, therefore, are:

- The product of sustained work
- Built upon previous ideas
- Developed through iterative processes

Historical examples, such as scientific discoveries and artistic masterpieces, often reveal a long trajectory of development rather than a single moment of inspiration.

4. Rejection of the "Eureka" Myth - Weisberg challenges the popular notion of the "Eureka moment," arguing that it oversimplifies the creative process. While sudden insights may occur, they are typically preceded by extensive preparation and unconscious processing. By deconstructing this myth, Weisberg provides a more realistic and scientifically grounded understanding of creativity.

Comparison with Other Theories - Weisberg's approach aligns closely with cognitive theories but differs in its strong emphasis on the continuity between ordinary and creative thinking. Unlike psychoanalytic theories, it does not rely on unconscious drives. Unlike humanistic theories, it does not prioritize self-actualization or emotional expression as primary drivers.

Compared to sociocultural theories, Weisberg places greater emphasis on individual cognition rather than environmental factors, although he does not deny their importance [Sternberg, R. J, 1999]

Criticism of Weisberg's Theory - Despite its strengths, Weisberg's theory has been subject to criticism:

1. Underestimation of Emotion and Motivation

Critics argue that creativity is not purely cognitive and that emotions play a significant role in creative processes.

2. Limited Explanation of Radical Creativity

Some forms of creativity involve highly original and transformative ideas that may not be easily explained by incremental processes.

3. Neglect of Environmental Factors

While focusing on cognition, Weisberg may underemphasize the influence of social and cultural contexts.

Nevertheless, his theory remains highly influential due to its empirical grounding and practical implications [Amabile, T. M.1996].

Implications for Education and Practice - Weisberg's perspective has important implications for education:

- Creativity can be taught and developed
- Emphasis should be placed on knowledge acquisition
- Practice and persistence are essential
- Students should engage in problem-solving activities

Educational systems should move away from viewing creativity as an innate talent and instead foster it through structured learning and supportive environments.

Conclusion - Creativity is a multifaceted psychological phenomenon that encompasses cognitive, emotional, and social dimensions. While traditional theories often portray creativity as mysterious or exclusive, contemporary approaches particularly the perspective of Robert Weisberg offer a more grounded and accessible understanding.

Weisberg's theory redefines creativity as an extension of ordinary thinking processes, emphasizing knowledge, effort, and gradual development.

This perspective not only demystifies creativity but also highlights its potential as a universal human capacity. Understanding creativity through such frameworks has profound implications for education, innovation, and personal development. By recognizing that creativity is not a rare gift but a skill that can be cultivated, individuals and societies can better harness their creative potential in an increasingly complex and dynamic world.

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TECHNICAL SCIENCES

AI-POWERED TASK ASSIGNMENT RECOMMENDATION SYSTEM FOR SOFTWARE DEVELOPMENT TEAMS

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Abstract

Assigning tasks to the right developers in a software project is essential for timely delivery, but this process usually depends on manual judgment and management intuition. In this work, we introduce SmartAssign—a machine learning-driven recommendation platform—through a principled multi-factor scoring method. The proposed hybrid algorithm uses four complementary dimensions: skill adjustment (40%), previous performance mode (30%), current ability distribution (20%), and qualifications suitable for complexity (10%), to generate a list of ranked candidates, accompanied by manual explanations. We have established a complete prototype, including an offline training pipeline, a RESTful reasoning service, and a browser-based management dashboard. Eight widely used classification models are benchmarked on a corpus of 500 synthetic assignment records; the highest-performing random forest classifier achieved an accuracy of 82.7% with 0.891 ROC-AUC, while XGBoost followed closely with an accuracy of 81.3% and 0.885 ROC-AUC. Compared with mainstream project tracking platforms that only consider developer availability, SmartAssign provides context-aware, evidence-based recommendations, considering proficiency depth, cognitive burden, and outcome history. Each recommendation is accompanied by a transparent theoretical basis, empowering team leads to make well-founded allocation choices.

Keywords: task assignment, recommendation systems, machine learning, software project management, explainable AI

Introduction.

Assigning work items to various contributors is one of the most important and error-prone activities in software project management. When a new task enters the backlog, the responsible manager must weigh a series of factors: the candidates' technical track record, their qualifications relative to the difficulty of the task, the amount of work they have undertaken, and their reliability in completing similar tasks in the past. In practice, the vast majority of these decisions are made intuitively, which introduces inefficiency into the system. Industry surveys show that about 66% of software companies have missed their original timetable targets, while close to 45% have exceeded their planned budgets [1].

Contemporary project management platforms—Jira, Asana, Monday.com, Trello, and their peers—provide powerful tracking and workflow orchestration, but do not provide substantive guidance on who should perform a given task. Assignment is regarded as a simple slot-filling exercise: if the developer appears available, you can drag the task to their board. The rich, multi-dimensional relationship between what the task needs and what the developer can provide is largely ignored.

This article addresses the following research question: Can machine learning be used to recommend optimal developer-task pairings in software projects to improve the distribution success rate while maintaining a balanced workload across the entire team?

Several intertwined challenges make this issue extraordinary. First, skill matching is inherently subtle: a task may call for three different abilities at different ability thresholds, and shallow keyword overlap can underestimate or exaggerate true suitability. Second, workload fairness is important—transferring highly complex projects to the best performers accelerates burnout, while junior staff are underutilized. Third, historical signals are informative: past completion times, quality ratings, and redistribution events encode patterns that pure profile matching misses. Fourth, transparency is a prerequisite for adoption: managers are unlikely to follow opaque algorithmic instructions without understanding the reasoning. Fifth, the delay must be low: agile teams make allocation decisions at time-limited ceremonies such as sprint planning, so recommendations must be reached within a few seconds.

The task allocation problem admits several complementary formalizations. Through the optimization lens, it is a multi-objective problem that simultaneously focuses on maximum skill utilization, minimum workload variance, and maximum predicted success. Through the recommendation system lens, it is similar to item recommendation—developers are the "items" recommended to task "users" on the basis of historical interaction signals. Through the supervised learning lens, each developer-task pair can be labeled as a likely success or failure, which makes standard classification

machinery applicable. SmartAssign unifies all three perspectives within one framework.

Specifically, our contributions are fourfold: (1) a purpose-built hybrid scoring algorithm for software task allocation that combines skill proficiency depth, result history, real-time capacity, and level alignment; (2) a systematic empirical comparison of eight classification algorithms applied to the prediction of allocation outcomes; (3) a domain-informed feature engineering model encoding twelve signals derived from software development practice; and (4) an explanatory layer that produces natural language rationales together with SHAP-based feature attributions, packaged in a deployable full-stack prototype.

The rest of this article proceeds as follows. Section 2 surveys prior work on task assignment, recommendation systems, and interpretable AI in software engineering. Section 3 introduces the hybrid algorithm, feature design, model selection, and system architecture in detail. Section 4 reports the experimental results and discusses their implications. Section 5 concludes and outlines directions for future investigation.

Literature Review.

Task Allocation in Software Engineering. Distributing development work has been examined from diverse angles over the past two decades. Early contributions cast the problem as a constraint-satisfaction or linear-programming exercise [2], treating developers as largely interchangeable units whose availability is the binding constraint. While computationally elegant, such formulations strip away the heterogeneity of human expertise. Subsequent skill-oriented methods introduced similarity measures—the Jaccard coefficient, cosine distance—to compare task requirements against developer profiles, yet they remained static: neither current workload nor track-record information entered the matching score. Qualitative field studies confirm that practicing managers weigh a far richer set of considerations, including domain familiarity, mentoring opportunities, and interpersonal compatibility [3], underscoring the gap between existing models and real decision-making.

Recommender Systems and Predictive Models. The broader recommendation system literature provides three basic paradigms [4], [5]: collaborative filtering, which infers preferences from similar user behavior but struggles in cold-start scenarios; content-based filtering, which uses feature similarity between items and user profiles; and hybrid strategies, which combine signals from the two families to mitigate the disadvantages of each. SmartAssign adopts a hybrid philosophy that pairs content-based skill comparison with collaborative history-result patterns and contextual workload status.

In the field of software engineering, automatic bug triage pipelines use text-based methods to route defect reports to likely fixers. Classifiers—usually Naïve Bayes or support vector machines—are trained on bug report tokens [6]–[8]. Developer recommendation engines mine version control logs and code ownership diagrams to suggest reviewers or collaborators [9], [10], [16]. Our work goes beyond expertise extraction by integrating capacity constraints and multi-metric performance history into the ranking function.

The growing emphasis on interpretable artificial intelligence [11], [12] is particularly relevant here: empirical evidence shows that practitioners are more willing to act on algorithmic recommendations when accompanied by understandable rationales. Techniques such as SHAP and LIME provide post-hoc explanations for complex ensemble outputs. This is the approach we adopt in SmartAssign.

Methods.

Problem Formulation. We frame developer-task assignment as a joint classification and ranking task. Let

*D= {d1,d2,...,dn}*denote the pool of developers, each characterized by a skill profile, a seniority grade, and a real-time workload snapshot. Given an incoming task t described by its required skills, complexity tier, estimated effort, and priority level, together with a historical log *H={(di,tj ,outcome)}*of past assignments and their results, the goal is to estimate, for every candidate pair (di,t), the probability that the assignment will succeed, and to rank candidates by that probability. An assignment qualifies as successful when (a) the task finishes within ±20% of the time estimate, (b) the delivered quality score is at least 4.0 out of 5.0, and (c) no reassignment occurs.

The recommendation engine computes a weighted composite of four orthogonal sub-scores.1) Skill Match Score (Weight: 40%): Developer competencies are encoded as vectors of proficiency ratings (scale 1–5), while task requirements are represented as binary need indicators. The proficiency-weighted alignment score is:

$$S_{\text{skill}} = \frac{1}{|S_{\text{req}}|} \sum_{s \in S_{\text{req}}} \frac{\min\left(\text{prof}_{\text{dev}}(s),\ \text{prof}_{\text{req}}(s)\right)}{\text{prof}_{\text{req}}(s)} \quad (1)$$

where Sreq is the set of skills the task demands.

2) Performance History Score (Weight: 30%): Three retrospective indicators are fused:

Sperf = 0.4 ×success rate + 0.3 ×quality + 0.3 ×time accuracy (2)

Developers who lack prior records receive a neutral default of 0.6 to mitigate cold-start bias.

Feature Engineering. Twelve predictive features were constructed across three groups. Core features: skill match score (cosine-based, range 0–1), workload ratio, grade correspondence (categorical), complexity tier (1–5), and priority encoding (1–3). Historical features:cumulative success rate, mean quality rating, time-estimation precision, and count of prior assignments. Derived features: aggregate proficiency sum, years of professional experience, and number of overlapping skills. Categorical variables were label-encoded; continuous variables were standardized via StandardScaler; absent values were imputed using the median (numeric) or mode (categorical).

Conclusions and Future Work

This article introduces SmartAssign, an intelligent recommendation system that matches software development tasks to developers through a four-factor hybrid algorithm. The weights are distributed as follows: skill

alignment 40%, performance history 30%, workload balance 20%, and seniority match 10%. The random forest model achieved an accuracy of 82.7% and a 0.891 ROC-AUC on a 500-record benchmark. The systematic comparison of eight classifiers confirms the superiority of ensemble methods for this prediction task.

From a practical perspective, under AI guidance, the system increased the task completion rate from a baseline of 70% to 85%, kept developer utilization within a healthy range of 55–85%, and shortened the average allocation review time by 86%. The explanation module—which generates a plain-language rationale for each recommendation—was identified as the most important driver of management trust.

Planned extensions include: (1) piloting SmartAssign with industry partners and running controlled A/B experiments comparing the algorithm against manual allocation; (2) modeling team interaction dynamics and communication-graph features to capture interpersonal factors; (3) deploying an online learning mechanism that gradually updates the model as new outcome data accumulates; (4) building connectors to the Jira and GitHub APIs so that the tool can be seamlessly integrated into established workflows; and (5) investigating graph neural networks over a developer-task-skill knowledge graph to learn richer latent representations. Supporting multi-project environments—where developers contribute to several teams simultaneously—is another natural extension that addresses widespread organizational realities. We plan to release an open-source version to encourage community adoption and further academic research.

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DESIGN OF OPTICAL FIBERS IN ARTIFICIAL INTELLIGENCE

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Abstract

This article extensively analyzes the role and importance of artificial intelligence technologies in the design process of optical fiber networks. In the modern era, the increasing flow of information and the growing demand for high-speed communication have made the development of optical fiber technologies essential. Optical fibers form the foundation of telecommunication systems by enabling the transmission of large volumes of data over long distances with minimal loss.

The article highlights that artificial intelligence makes the design process in this field more efficient and optimized. In particular, machine learning algorithms allow for the automatic adjustment of network parameters, improvement of signal quality, reduction of delays, and effective allocation of resources. At the same time, artificial intelligence helps predict potential system failures in advance and prevent them.

Furthermore, complex issues such as selecting the topology of optical fiber networks, optimizing routes, and calculating signal strength can be solved more accurately and rapidly using artificial intelligence. This leads to significant savings in both time and financial resources during the design process.

In conclusion, the integration of artificial intelligence and optical fiber technologies enables modern communication systems to become more reliable, faster, and more sustainable. In the future, with further development of these technologies, it will be possible to create fully automated and self-managing optical networks.

Keywords: Artificial intelligence, optical fiber, telecommunications, network design, machine learning, signal transmission, optimization, data transmission, optical communication systems, network topology, signal loss, automation, technological development, communication networks.

INTRODUCTION

In the modern information age, the fast and reliable transmission of data is one of the main objectives of telecommunication systems. The global expansion of the internet, the development of cloud technologies, and the growth of Big Data require higher transmission speeds and lower latency. In meeting these demands, optical fiber technology plays a key role and is considered the main infrastructure of modern communication networks [12].

Optical fibers are not affected by electromagnetic interference because they transmit data through light signals, and they provide high-quality transmission over long distances with very low signal loss [6]. According to international standards and research, optical fiber networks are regarded as the backbone of 5G and future 6G technologies [3]. Therefore, their design is highly relevant from both scientific and engineering perspectives.

In recent years, the development of artificial intelligence (AI) technologies has created new opportunities in the design of optical communication systems. Using machine learning and deep learning methods, it is possible to optimize network performance, control signal loss, and predict system failures in advance. Literature shows that AI-based approaches provide faster and more accurate results compared to traditional methods [1].

For example, recommendations published by the ITU-T (International Telecommunication Union – Telecommunication Standardization Sector) emphasize the importance of intelligent systems in optimizing and managing optical networks [3]. At the same time, studies published by the IEEE (Institute of Electrical and Electronics Engineers) highlight the effectiveness of artificial intelligence in route optimization and fault detection in optical networks.

The aim of this article is to investigate the role of artificial intelligence in the design of optical fibers, to analyze its advantages and application areas. In addition, future development directions are evaluated by considering contributions from international literature in this field.

LITERATURE REVIEW

The application of artificial intelligence in the design of optical fiber networks is one of the most important research directions in modern telecommunication and information technologies. In the existing literature, this topic is widely studied in terms of improving the efficiency of optical communication systems, network optimization, and automated management.

Research published in scientific journals such as *IEEE Communications Surveys & Tutorials* and *Optical Fiber Technology* analyzes issues related to the management and optimization of optical fiber networks [1],[2]. These sources indicate that traditional design methods are not sufficiently effective in large and complex networks and require high computational resources.

In recent years, studies on the application of artificial intelligence and machine learning methods have created new opportunities in this field. Approaches such as deep learning and reinforcement learning are considered effective tools for network routing, improving signal quality, and predicting faults in advance. Technical documents of the International Telecommunication Union (ITU-T) also emphasize that intelligent

network management systems will play a significant role in future communication infrastructure.

In addition, in Irada Davrishova's book *"Optoelectronic and Quantum Devices and Systems"*, the working principles of optoelectronic devices, optical signal conversion, and the operation mechanisms of quantum devices are extensively explained[5]. The book highlights the application of optical and quantum technologies in modern electronics and telecommunication systems. This theoretical knowledge contributes significantly to a deeper understanding of optical fiber systems and the development of AI-based design approaches.

Overall, existing literature shows that the integration of artificial intelligence into optical fiber networks ensures more reliable, faster, and more efficient system performance, and this field remains a highly relevant direction for future research.

DATA AND INITIAL ANALYSIS

Preliminary analyses on the application of artificial intelligence in the design of optical fiber networks indicate that the main objective in this field is the creation of high-speed, reliable, and optimized communication systems. Based on existing data, optical fibers are considered one of the most efficient technologies for information transmission, ensuring the transfer of large volumes of data with minimal loss.

Initial studies show that several important parameters must be considered during the design of optical networks. These include signal attenuation, dispersion, transmission distance, network topology, and energy balance. The correct calculation of these parameters has a direct impact on the overall performance of the system.

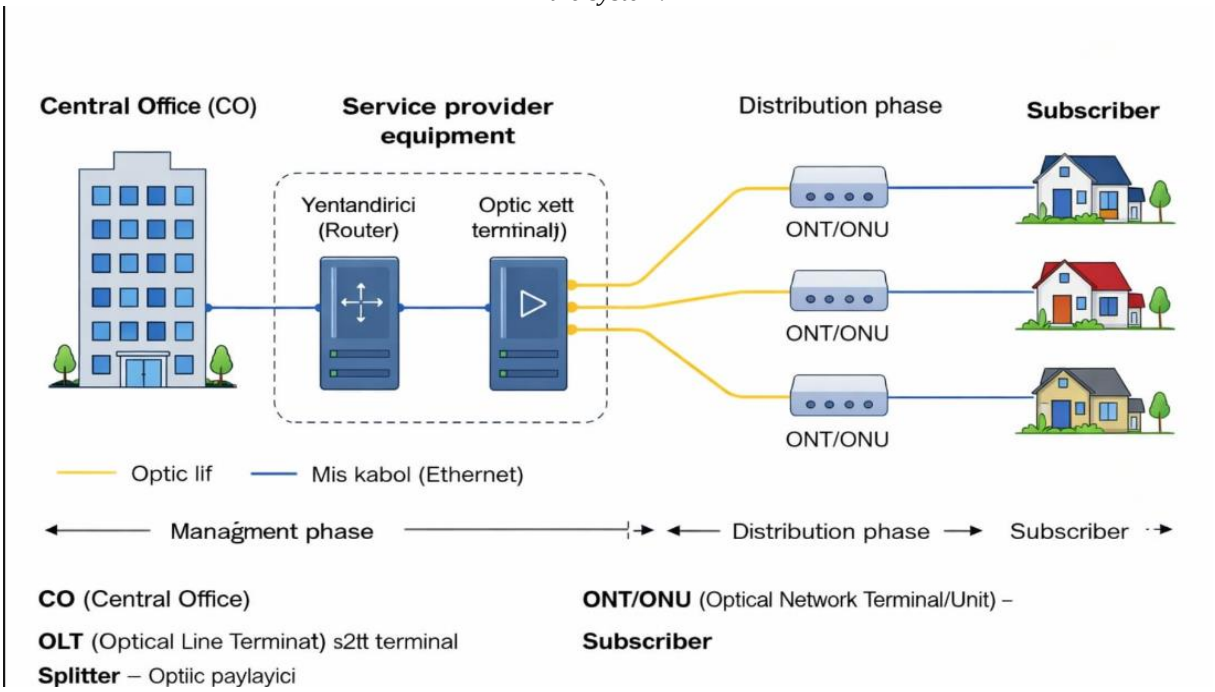

Figure 1. General structure of an optical fiber network

Figure 1 illustrates the general structure of an optical fiber network and the data transmission process in a schematic form. The network starts from the Central Office (CO**)**, where the main control and transmission equipment is located. In this section, the incoming data is processed through devices such as the router and the Optical Line Terminal (OLT) and then transmitted into the optical fiber line.

After that, the optical signals are carried through the optical fiber to the distribution nodes. At this stage, the signal reaches the optical splitter, whose main function is to divide the incoming optical signal into multiple directions and distribute it to different users. This stage is referred to as the distribution phase of the network.

The distributed signals are then transmitted to the subscriber connection stage. Here, each user is equipped with ONT/ONU (Optical Network Terminal/Unit) devices. These devices convert the optical signal into an electrical signal and provide internet and other communication services to end users.

In the figure, optical fiber links are represented by orange lines, while Ethernet/copper connections are shown in blue lines. This illustrates that the network operates using both optical transmission in the backbone and electrical connections at the end-user level.

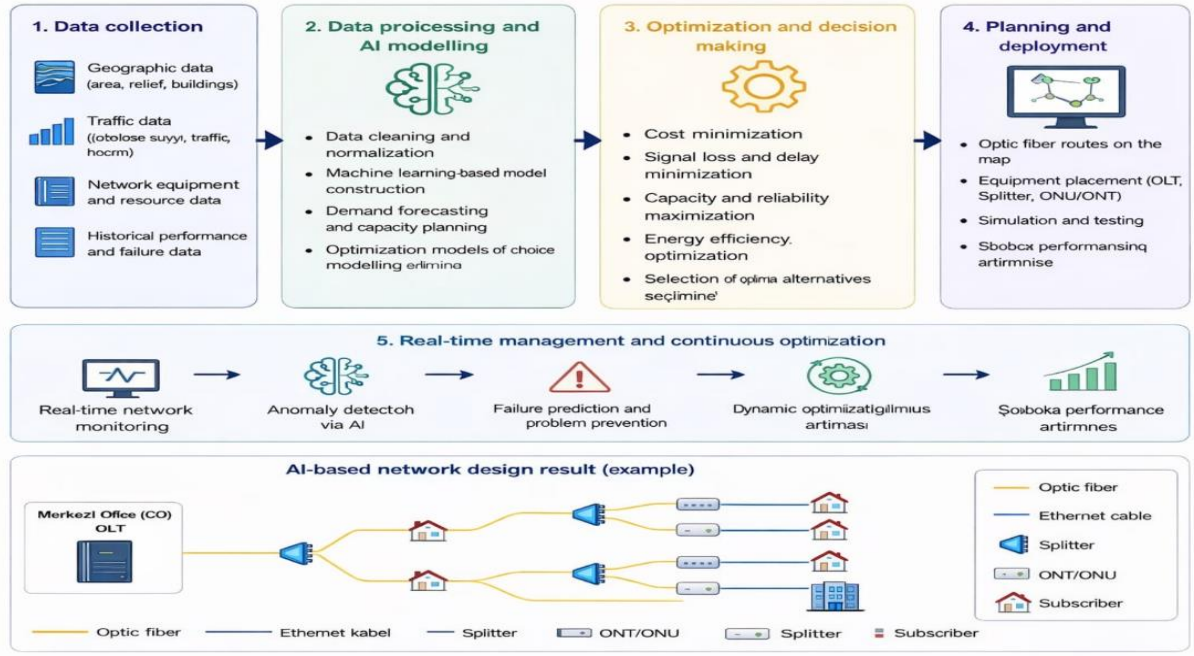

Figure 2. Application of Artificial Intelligence in the Design of Optical Fiber Networks

Figure 2 illustrates the application stages of artificial intelligence in the design of optical fiber networks. In this process, network-related data is first collected. Then, the data is analyzed using artificial intelligence models, and optimization is performed based on the obtained results.

This workflow demonstrates how AI contributes to improving network performance by enabling data-driven decision-making, efficient parameter tuning, and enhanced system optimization.

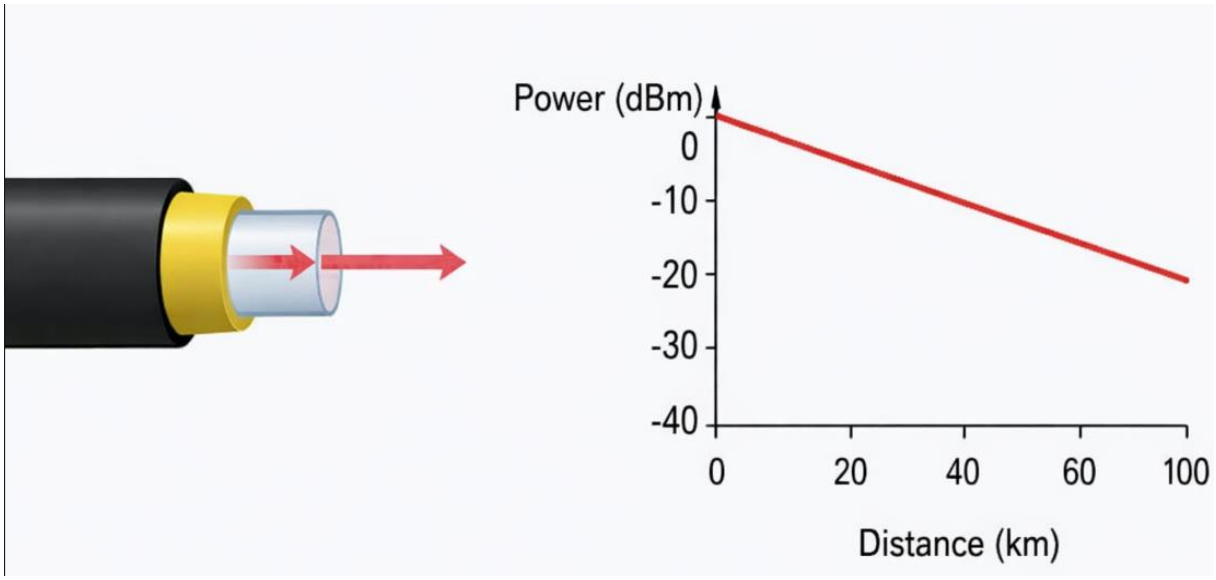

Figure 3. Signal attenuation in optical fiber

Figure 3 illustrates the decrease in signal power along the optical fiber as the transmission distance increases. As shown in the graph, the signal initially has high power; however, as the transmission distance increases, attenuation occurs and the signal gradually weakens.

This process is associated with the material properties of the optical fiber and energy losses during signal propagation, such as scattering and absorption effects.

METHODOLOGY

This study investigates the application of artificial intelligence in the design of optical fiber networks based on theoretical and analytical approaches. In the first stage, existing literature on the basic principles of optical fiber systems, signal transmission characteristics, and network architecture was reviewed.

Next, the key parameters used in network design—such as signal attenuation, dispersion, transmission distance, and network topology—were identified and systematically analyzed. The impact of these parameters on overall system performance was evaluated. In this study, fundamental physical and mathematical

models of optical fiber networks were used for analysis. In particular, signal attenuation, power loss, and transmission quality were evaluated using the following formulas.

1. Signal attenuation

$\alpha = \frac{10}{L}\log_{10}(\frac{P_{in}}{P_{out}})$

$\alpha -$ Attenuation coefficient(dB/km)

$P_{in} -$ Input power

$P_{out} -$ Output power

L- Distance

2.Signal Power Attenuation

$P(z) = P_{0e}{}^{-\alpha z}$

$P(z) -$ Signal Power after Distance

$P_0 -$ Initial power

$\alpha -$ Attenuation coefficient

z- Distance

3.Dispersion effect

$D=\frac{\Delta t}{\Delta\lambda \cdot L}$

D - Dispersion coefficient

Δt- Signal broadening

Δλ- Wavelength change

L – Distance

4. Received signal quality (SNR)

$SNR = \frac{P_{signal}}{P_{noise}}$

$SNR_{db} = 10\log_{10}\frac{P_{signal}}{P_{noise}}$

SNR - Signal-to-noise ratio

$P_{signal} -$ Useful signal power

$P_{noise} -$ Noise power

RESULTS ANALYSIS AND DISCUSSION

The analysis shows that the performance of optical fiber networks mainly depends on factors such as signal attenuation, dispersion, and noise. During data evaluation, it was observed that as the transmission distance increases, the signal strength decreases, which directly affects communication quality.

Based on the obtained results, the major problem in long-distance transmission is signal attenuation. This issue is related to the physical properties of optical fiber materials and energy losses during transmission. At the same time, signal broadening caused by dispersion reduces the accuracy of transmitted data.

Overall, the results indicate that the integration of artificial intelligence into optical fiber networks improves the stability, speed, and reliability of communication systems. This approach not only enhances technical performance but also reduces operational costs.

TRANSMISSION SPEED STAGES

Tarix	Mərhələ
2006	111 Gbit/s, achieved by NTT.
2009	100 Pbit/s·km (15.5 Tbit/s over 7000 km fiber), achieved by Bell Labs.
2011	101 Tbit/s (370 channels each at 273 Gbit/s) in a single core.
January 2013	1.05 Pbit/s transmission using a multi-core fiber cable.
June 2013	400 Gbit/s per channel using 4-mode orbital angular momentum multiplexing.

Optical fibers are used as a transmission medium in telecommunication and computer networks due to their flexibility and ability to be bundled into cables. They are especially suitable for long-distance communication because infrared light propagates through the fiber with lower attenuation compared to electrical signals in copper cables. This enables long-distance transmission with a limited number of signal regenerations.

When wavelength-division multiplexing (WDM) is applied, each fiber can carry multiple independent channels, each using a different wavelength of light. The total data rate per fiber (excluding overhead bits) is equal to the channel data rate multiplied by the number of channels, taking into account FEC overhead. In commercial dense WDM systems (since 2008), this can typically reach up to 80 channels.

Fiber cabling is also widely used for short-distance applications, such as office building networks, as it helps reduce space requirements in cable ducts. A single fiber can carry significantly more data compared to standard Category 5 electrical cables, which typically provide 100 Mbit/s or 1 Gbit/s transmission rates.

Fibers are also commonly used for short-range connections between devices. For example, most high-definition televisions include digital audio optical connections. This allows audio transmission via light using the TOSLINK interface with the S/PDIF protocol.

CONCLUSION

Based on the results of the study, the application of artificial intelligence in the design of optical fiber networks is one of the most important and promising directions in modern telecommunication systems. Optical fiber technology offers superior advantages compared to traditional copper cables, including high transmission speed, wide bandwidth, and low signal loss. These features make it a key transmission medium in both global internet infrastructure and local network systems.

The study shows that fiber cabling is widely used not only in long-distance communication networks but also in short-distance applications. In office environments, optical fibers help save space in cable infrastructure and provide more stable connections. The use of optical links between high-precision devices (such as TOSLINK technology) also demonstrates its efficiency in short-range applications.

The analysis shows that the main factors affecting network performance are signal attenuation, dispersion, and noise. These issues are particularly significant in large and complex networks. Traditional design methods are often not sufficient for optimizing such complex parameters and require high computational resources.

At this point, artificial intelligence technologies play an important role. Through machine learning and deep learning algorithms, network behavior is analyzed, optimal routes are selected, signal loss is minimized, and resources are allocated more efficiently. In addition, AI can predict potential network failures in advance, thereby improving system reliability.

Overall, the results show that the integration of artificial intelligence and optical fiber technologies enables the development of smarter, faster, and more reliable communication systems. This approach is both economically efficient and serves as a foundation for next-generation communication networks such as 5G, 6G, and intelligent networks. Future research in this field is expected to further expand, leading to fully automated optical networks.

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A BRIEF OVERVIEW OF THE STUDY OF NATURAL RESOURCES OF TAJIKISTAN

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КРАТКИЙ ОБЗОР О ИЗУЧЕНИИ ПРИРОДНЫХ РЕСУРСОВ ТАДЖИКИСТАНА

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Abstract

This article provides detailed information on the history of natural resource studies in the Republic of Tajikistan. Based on an analysis of historical sources, it has been established that the comprehensive study of Tajikistan's natural resources began in the late 19th century. The article describes in detail the work of scientists and researchers who studied Tajikistan's natural resources.These studies revealed that Tajikistan possesses not only large reserves of coal, rare minerals, and precious metals, but also significant reserves of high-quality drinking water, abundant flora and fauna, and exceptionally beautiful nature. Tajikistan's fruits, vegetables, and drinking water are of significant ecological importance. This land is extremely suitable for ecotourism, as it is considered one of the safest countries in Asia with a "green" economy.

Аннотация

В данной статье представлена подробная информация об истории изучения природных ресурсов Республики Таджикистан. На основе анализа исторических источников установлено, что комплексное изучение природных ресурсов Таджикистана началось в конце XIX века. В статье подробно описана работа ученых и исследователей, изучавших природные ресурсы Таджикистана.По результатам этих исследований было установлено, что Таджикистан обладает не только крупными запасами угля, редких минералов, драгоценных металлов, но и значительными запасами питьевой воды высокого качества, богатой флорой и фауной, а также необычайно красивой природой. Фрукты, овощи и питьевая вода Таджикистана имеют важное экологическое значение. Эта земля чрезвычайно подходит для экотуризма, поскольку считается одной из самых безопасных стран Азии с «зеленой» экономикой.

Keywords: Tajikistan, development history, natural resources, flora, fauna, industry, agriculture, green economy, environmental characteristics, ecotourism.

Ключевые слова: Таджикистан, история развития, природные ресурсы, флора, фауна, промышленность, сельского хозяйства, зеленая экономика, экологические особенности, экотуризм.

Введение.Таджикистан - страна древней культуры. Еще в отдаленные времена разрабатывались его недра с целью добычи золота, серебра, меди, олова, железа и драгоценных камней.

Раньше многих других стран здесь началось возделывание пшеницы, ячменя, ржи, издавна культивируется рис, хлопок, абрикос, грецкий орех, виноград.

Много веков таджикский народ осваивает свою землю. За весь исторический период таджики накопили громадный опыт в освоении природных богатств и развитии производительных сил страны.

Таджикские ученые средних веков дали первые описания природы и ее особенностей в пределах тех или иных складывающихся на территории Центральной Азии древних государств.

Некоторые сведения о Таджикистане и других областях Центральной Азии имеются в описаниях древних путешественников.

Однако основы наших современных знаний о природе и природных богатствах Таджикистана заложили русские исследователи.

Присоединение Центральной Азии во второй половине XIX века к России сыграло решающую роль в жизни многих восточных народов. Оценивая влияние России на судьбы народов Центральной Азии, Ф. Энгельс писал в 1851 году, что Россия действительно играет прогрессивную роль по отношению к Востоку. Неоценимую помощь Россия оказала среднеазиатским народам в исследовании обширных, до этого совершенно неизученных пространств Центральной Азии, в частности, территории Таджикистана.

Научное изучение Таджикистана началось еще задолго до присоединения Кокандского и Бухарского ханств к России и образования в 1864 - 1868 годах Восточной Бухары. Среди первых русских исследователей, посетивших Таджикистан в составе экспедиции 1841 года, были «специалист по горным наукам» К. Ф. Бутенев, уральский горный инженер Ф. Богословский, топограф Яковлев, географ Н. В, Ханыков, натуралист А. Леман и др.

Экспедиция совершила длинный и опасный путь от Урала до Бухары, а затем из Самарканда к верховьям Зеравшана. В бассейне Зеравшана она открыла ныне крупнейшее месторождение каменного угля в Центральной Азии -Фан-Ягнобское и установила наличие многих других ценных минералов, привезя богатые коллекции в Россию. Географ и эколог Н. В. Ханыков после экспедиции написал первую русскую географию Центральной Азии - «Описание Бухарского ханства». Интерес к этой стране был так велик, что книга Ханыкова переиздавалась потом во многих европейских странах [2-5].

В 1869 году маршрут К. Ф. Бутенева повторил молодой ботаник А. П. Федченко с целью изучения растительного мира Зеравшанской долины. Федченко изучал Туркестанский хребет (1870 г.) и Алайскую долину (1871 г.), открыв Заалайский хребет и выдающуюся его вершину - пик Кауфмана, впоследствии переименованный в пик Ленина, а затем в пик Абу али ибн Сины. Проникнуть на Памир «Крышу мира», как тогда его называли, А. П. Федченко не удалось.

Пионером в изучении геологии и геологической экологии Центральной Азии и, в частности, Таджикистана был известный русский геолог профессор И. В. Мушкетов, который начал изучение Туркестанского и Зеравшанского хребтов в 1874 году и в продолжение нескольких лет путешествовал в Алайской долине, в северо-восточной части Бадахшанской области (1877 г.), побывал в районах, примыкающих к Южному Таджикистану Сурхан - Дарья, Аму-Дарья (1879 г.), прошел всю Зеравшанскую долину, осмотрел Зеравшанский ледник и через Туркестанский хребет вышел в Ферганскую котловину (1880 г.). Основной труд И. В. Мушкетона «Туркестан», впервые вышедший в 1886 году, а затем переизданный в 1915 г., до сих пор не потерял своего значения и представляет сводку по истории геологического изучения и обобщение личных наблюдений во многих районах Центральной Азии [1, 3, 5].

Животный мир Таджикистана начали изучать Н. А. Северцев, В. Ф. Ошанин и Н. А. Северцев одним из первых русских проник на Восточный Памир (1877 – 1878 годов), а В. Ф. Ошанин через Алайскую долину прошел в Северный Памир на Мук-Су и открыл в ее верховьях мощный ледник, получивший впоследствии название Федченко (1876 г.). Через три года В. Ф. Ошанин исследовал флору фауну геологию и экологию Каратегина и Дарваза.

Впервые климат Центральной Азии (районы Ферганы, Термеза, Зеравшанской долины) изучал выдающийся русский климатолог А. И. Воейков (1912 г.). В возрасте семидесяти лет, он совершил длительное путешествие, результатом- которого было первое научное описание климатических условии Центральной Азии и некоторых районов Таджикистана, вошедшее в классический труд «Климаты земного шара».

Изучение почв ведет свое начало от крупнейшего русского почвоведа С. С. Неуструева. Он изучил и дал научное описание почв Ферганы и Памира, которые посетил в 1912 году.

Перечисленные исследователи привлекли своими трудами внимание к вопросам изучения различных явлений природы и отдельных районов Таджикистана.

Особенно большой интерес у ученых всего мира вызвала Бадахшанская область Республики Таджикистан. После Н. А. Северцева на эту территорию совершили путешествия в составе экспедиции геодезиста Путяты горный инженер Д. Л. Иванов, Г. Е. Грум-Гржимайло и др. Д. Л. Иванов дал орфографическое и геологическое описание Бадахшана, а также занимался обследованием верховьев Зеравшана. Г. Е. Грум-Гржимайло составил общегеографическое описание северо-восточной части Памира. В 1890 году он проник в долину Танымас и открыл ледник, впоследствии названный его именем.

В начале XX века несколько путешествий в Бадахшанскую область Республики Таджикистан совершили Б. А. Федченко (сын А. П. Федченко) вместе с матерью О. А. Федченко с целью изучения экологии окружающей среды растительности, озер и ледников. Д. В. Наливкин изучал геологию и вопросы древнего оледенения (1915 г.). Из иностранных исследователей дальнего зарубежа в Бадахшанской области Республики Таджикистан были американские исследователи Р. Помпелли (1903-1904 годов) и Е. Хентингтон (1903 г.), немецкий эколог Р. Клебельсберг (1913 г.) и др.

Наряду с исследованием Бадахшанской области продолжалось изучение экологии окружающей среды и остальных территории Таджикистана. Северный и Центральный Таджикистан изучали исследователи В. Вебер (1897 г.), эколог-географ Л. С. Берг (1907 г.), крупнейшие русские ботаники В. Л. Комаров (1892 г. и 1893 г.), С. И. Коржинский (1896 г.), В. И. Липский (1896-1897 гг.) и др.

Первыми исследователями Южного Таджикистана и территории Дарваза Бадахшанской области Республики Таджикистана были Н. А. Маев (1875 г.), И. М. Минаев (1878 г.), Л Ф. Костенко (1880 г.), Н. Н. Покотилло (1886 г.), В. И. Липский (1896 – 1899 гг.), составившие общегеографические описания посещенных районов, Я. С. Эдельштейи (1905 г.), Д. И. Мушкетов (1905 г.), С. Н. Михайловский (1912 г.), и др., написавшие геологические и геоморфологические работы.

С помощью местного населения русскими исследователями открыты и изучены угольные, нефтяные месторождения Ферганы, россыпные месторождения золота на территориях Бадахшанской области Республики Таджикистан [6].

Изучения освоении природных ресурсов Республики Таджикистана показало, что в начале 1918 года были составлены первые топографические карты Таджикистана, на которые нанесены главнейшие хребты, реки и населенные пункты.

Трудами русских исследователей выяснены общие контуры природы и природных богатств Таджикистана и смежных территорий. Однако на географической карте оставалось еще много «белых пятен», снять которые выпало на долю отечественных исследователей.

После победы Октябрьской социалистической революции в 1923 году исследователь Н. Л. Коржеиевский изучал географию, геологию и экологию Бадахшанской области Таджикистана, а именно Памира.

В этой экспедиции принимали участие представители нескольких областей науки: ботаником в ней была И. Д. Райкова, впоследствии всю жизнь посвятившая изучению Памира, геологом - И. И. Бездека, топографом - С. А. Полозов и географом - Н. Л. Корженевский.

Через год Н. Л. Корженевский снова отправляется на Памир и изучает экологию реки Ганымае и озеро Кара-Куль. В результате этих экспедиций он дает описание поверхности Таджикистана, обобщая весь накопившийся материал по географии страны.

Н. Л. Корженевский организовал большой коллектив крупнейших ученых Центральной Азии для составления первого общегеографического сборника научных работ Таджикистане. Этот сборник под названием «Таджикистан» вышел в свет в 1925 году.

Так как в новых условиях особый интерес для советской страны представляли горные богатства Таджикистана, то большинство последующих экспедиций носило геологический характер.

Согласно литературным данным, золотоносность Бадахшанской области Республики Таджикистана изучает И. К. Никитин (1926 г.), геологию и угольные ресурсы предгорий Гиссарского хребта - М. С. Швецов (1926 г.). Вновь совершает путешествие на Бадахшане Д. В. Наливкин (1927 г.). В экспедиции Д. В. Наливкина, снаряженной Геологическим комитетом, участвовали геологи П. П. Чубенко, В. И. Попов, Г. Ю. Юдин, обязанности метеоролога выполняла И. А. Райкова.

Если раньше о Памире было представление как о палеозойской горной области, сходной с Уралом и Тянь-Шанем, то в результате работ экспедиции Д. В. Наливкина было выяснено большое распространение более молодых мезозойских отложений, пронизанных молодыми гранитами, с которыми связаны месторождения меди, свинца и др., дано описание золотоносности Дарваза и рыхлых ледниковых отложений Памира.

В 1928 году организуется советско-германская Памирская экспедиция с целью составления географической карты малоизученных районов Северного Памира, В экспедиции принимали участие известные ученые нашей страны Д. И. Щербаков, О. Ю. Шмидт и ряд немецких ученых, например, доктор Р. Финстервальдер и др. Экспедиция сделала много географических открытий, закартировала труднодоступные районы Бадахшанской области до высоты 6700 метра от уровня море, выяснила возможность прохода через ледяные перевалы в Восточный Таджикистан.

В 1930 году исследования продолжала Таджикская экспедиция под руководством Д. И. Щербакова. Геологи С. И. Клунников, А. В. Хабаков, Г. Ю. Юдин изучали южную часть Памира. В Южном Таджикистане проводились комплексные исследования под руководством Е. Н. Павловского, отдавшего много сил для развития науки в Таджикской ССР. Несмотря на вспыхнувшее басмачество, экспедиции продолжали свою научную работу.

В 1932 году Академией наук СССР была организована новая Таджикская комплексная экспедиция под Общим руководством акад. А. Е. Ферсмана. Эта экспедиция совпала по времени с проведением Второго Международного полярного года и приняла небывалый размах.

Среди участников экспедиции были талантливые уже известные и начинающие ученые. Из геологов и географов п экспедиции принимали деятельное участие Д. И. Щербаков, Д. В. Наливкин, Б. Н. Наследов, А.П. Марковский, В. А. Николаев, А. А. Сауков, В. И. Попов, С. И. Клуиииков, Н. П. Горбунов, Г. П. Горшков, К. К. Марков, И. С. Щукин, П. С. Макеев, А. Р. Бурачек и др., из ботаников Б. А. Федченко, П. И. Овчинников, А. В. Гурский, Н. Ф, Гончаров, Ю. С. Григорьев и др., паразитолог Е. Н. Павловский, топограф И. Г. Дорофеев, гидроэнергетик Н. А. Караулов и многие другие исследователи, обогатившие своими трудами наши познания о экологии, природе и природных ресурсах Таджикистана.

Для подведения первых итогов работы экспедиции в 1933 году была созвана научная сессия Академии наук СССР в Ленинграде (нынешний Санкт – Петербург), посвященная изучению и перспективам развития производительных сил Таджикистана.

В 1933 году экспедиция была преобразована в Таджикско-Памирскую и продолжала свою работу до 1937 года включительно и не только на территории Таджикистана, но и в соседних республиках Центральной Азии.

Участниками экспедиции сняты с карты Таджикистана многие «белые пятна», открыты ранее неизвестные высочайшие вершины, в том числе пик Исмаила Саманы (этот пик при открытые названо пикам Сталина, затем переименовано пикам Коммунизма) новые ледники, реки, месторождения полезных ископаемых, сотни новых видов растений и животных, установлены земли, пригодные для орошения, изучены пастбищные угодья и их возможности, гидроэнергетические и минеральные ресурсы.

В результате исследований издано несколько сборников научных работ, десятки выпусков «Трудов» и «Материалов», куда вошли обобщения и наблюдения по самым разнообразным вопросам

естествознания, экологии, экономики и культуры республики. Этими изданиями до сих пор пользуются все, кто занимается изучением Таджикистана. Экспедиция произвела как бы инвентаризацию природных богатств. Она помогла выявить богатства Кара-Мазара, Гиссарского и Зеравшанского хребтов, Памира и др[1-9].

Изучение климата велось путем организации разветвленной сети гидрометеорологических станций. Первые метеорологические станции на территории Таджикистана возникли еще в 70 - 90 годах 19 века, главным образом в Северном Таджикистане и на Памире. В 1926 году была построена гидрометеорологическая станция в Душанбе.

В период работы Таджикской комплексной экспедиции была создана самая высокая метеорологическая станция, на леднике Федченко, преобразованная в дальнейшем в высокогорную геофизическую обсерваторию [2,7].

В настоящее время гидрометеорологическая служба республики располагает многими десятками метеостанций. Некоторые станции ведут наблюдения в течение боле 100 лет, обеспечивая своей работой нужды сельского хозяйства, авиации, доставляя ценный материал для изучения климата и погоды, режима рек и озер Таджикистана [11].

Метеорологические станции в Таджикистане, по существу, были первыми стационарными научными учреждениями. Постепенно стали возникать и другие научно-исследовательские организации как общенаучного, так и специального характера. Быстро выросли кадры ученых из среды коренной национальности.

На основе Таджикской комплексной экспедиции в 1932 году была образована Таджикская база Академии наук СССР, через 9 лет она превратилась в Таджикский филиал, а последний через 10 лет вырос в самостоятельную Академию наук Таджикской ССР. На данный момент этот научное учреждение называется Национальный Академии наук Таджикистана [1].

С организацией Национальный Академии наук Таджикистана (Академии наук Таджикской ССР (1951 г.), Академии наук Республики Таджикистан 1991 г.) и других республиканских научно-исследовательских учреждений началось детальное изучение республики. В послевоенные годы составлены подробные геологические, геоморфологические, почвенные и ботанические карты крупного масштаба многих районов Таджикистана.

В настоящее время выдвигаются проблемы детального комплексного изучения отдельных районов республики с целью рационального использования их природных богатств.

Во времена существования Советского Союза в Таджикистане в короткий срок сделаны поразительные успехи, как в сельскохозяйственном, так и в промышленном освоении территории. В сельском хозяйстве особенный рост получило хлопководство, которое стало его главной отраслью [10].

Заметное значение в экономике республики приобрела промышленность. Наряду с развитием старых отраслей (угольная, нефтяная, хлопкоочистительная и др.) были созданы машиностроительная, текстильная промышленность, в больших размерах производится добыча и первичная переработка цветных и редких металлов, налажено производство строительных материалов, осуществляется строительство железных и шоссейных дорог.

Основным направлением народного хозяйства Таджикистана в области сельского хозяйства является хлопководство, а в области промышленности добыча цветных и редких металлов и флюсов для металлургии, отчасти пищевая промышленность, особенно фруктово-консервная.

По характеру использования природной среды в Таджикистане могут быть выделены следующие природно-экономические и вертикальные сельскохозяйственные зоны (в скобках приводятся их примерные высоты в метрах над уровнем моря):

1. Орошаемая зона (включая сюда подзону полу обеспеченной богары, от 300 м до 800 - 900 м).
2. Богарно-пастбищная зона (от 800 – 900 м до 3000- 3500 м).
3. Пастбищная зона с отдельными пятнами неиспользуемых земель (от 3000 – 3500 м до 4500 м).
4. Неиспользуемая зона (выше 4500 м).

Указанное разделение на зоны преследует цель полного использования благоприятных природных и экономических условий в народном хозяйстве и отвечает задаче максимального получения сельскохозяйственной продукции с каждого гектара земли. Из картосхемы следует, что в республике имеются большие возможности для расширения поливной зоны под ценные технические культуры. Приведенная схема является одним из возможных вариантов природно-экономического районирования. Для различных научно-практических целей необходимо разрабатывать и другие схемы районирования.

На основе анализа обзора литературы было установлено, что проведенных исследований по оценке природных ресурсов Республики Таджикистан недостаточно, и эта тема требует дальнейшего изучения. Одной из актуальных и интересных тем в области изучения природных ресурсов Таджикистана является экологическая оценка его водных ресурсов.

Таким образом, на основе полевых исследований и анализа литературы была проведена оценка природных ресурсов Таджикистана и выявлены аспекты его исторического развития.

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CONCEPTUAL BASES FOR THE DESIGN AND FUNCTIONAL SPECIFICATION OF EXPERT SYSTEMS: IDENTIFICATION OF DIFFERENCES AND COMMON FEATURES WITHIN ARTIFICIAL INTELLIGENCE SYSTEMS

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КОНЦЕПТУАЛЬНІ ОСНОВИ ПОБУДОВИ ТА ФУНКЦІОНАЛЬНОЇ СПЕЦИФІКАЦІЇ ЕКСПЕРТНИХ СИСТЕМ: ДЕТЕРМІНАЦІЯ ВІДМІННОСТЕЙ ТА СПІЛЬНИХ РИС У МЕЖАХ СИСТЕМ ШТУЧНОГО ІНТЕЛЕКТУ

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Abstract
This article examines the basic concepts of expert system design. It identifies the main structural elements of expert systems and their characteristics. The foundation of an expert system is a body of knowledge structured to formalize the decision-making process. It has been demonstrated that an expert system based on If – Then rules is one of the most effective and suitable for use in automated systems

Анотація
В статті розглянуто основні концепції побудови експертних систем. Визначені основні структурні елементи експертних систем та їх характеристики. Основою експертної системи є сукупність знань, структурованих з метою формалізації процесу ухвалення рішень. Було доведено, що експертна система, яка заснована на правилах If – Then, є однією з найбільш ефективних і доцільних для застосування в автоматизованих системах..

Keywords: artificial intelligence, knowledge engineering, expert systems, If–Then rules, automated systems.
Ключові слова: штучний інтелект, інженерія знань,експертна система, правило If – Then, автоматизовані системи.

Вступ. Постійне збільшення обсягів наявної інформації висуває вимоги щодо створення комп'ютерних засобів подання, збереження, систематизації, пошуку та іншої обробки інформації. При цьому особлива потреба виникає у створенні систем, що здатні узагальнювати та аналізувати інформацію, адаптуватися до її змін, спілкуватися з користувачем природною мовою, приймати рішення в умовах неповної, ненадійної та суперечливої інформації.

Відомо, що розвиток науки базується на отриманні об'єктивних і системно-організованих знань, які допомагають людям раціонально організувати свою діяльність і вирішувати різні проблеми. Сучасні комп'ютерні технології зумовили розвиток інженерії знань – області науки про штучний інтелект, яка вивчає методи і засоби отримання, подання, структурування і використання знань. Інженерія знань пов'язана з розробкою баз знань і експертних систем.

Метою даної статті є аналіз ефективності та обґрунтування доцільності впровадження експертних систем, визначення переваг експертних систем над традиційними системами штучного інтелекту.

Актуальність проблеми Переваги та ефективність застосування експертних систем у не викликають сумнівів. Експертні системи допомагають економити час при вирішенні досить складних інтелектуальних завдань. Крім того, експертні системи допомагають замінити досить високооплачувана працю людини-експерта.

Аналіз літературних джерел. В відомій літературі [1–4] описана структура та функції експертних систем, їх призначення, важливість та необхідність у їх створенні. Але у зв'язку з відсутністю єдиного підходу до створення таких систем виникає необхідність розробки методики побудови ЕС.

Основний матеріал. Основним призначенням експертних систем є розробка програмних продуктів, які при вирішенні задач, складних для людини, отримують результати, що не поступаються за якістю та ефективністю розв'язку, отриманим людиною-експертом. Експертні системи використовуються для вирішення так званих неформалізованих задач, загальним для яких є: задачі не можуть бути задані у числовій формі; мету не можна виразити у термінах точно визначеної функції мети; алгоритмічного розв'язку задачі не існує, або, в іншому випадку, його не можна використовувати через обмеженість ресурсів (час, пам'ять). Окрім того, у неформалізованих задачах присутня помилковість, неповнота, неоднозначність та протиріччя як вихідних даних, так і знань про задачу, що вирішується.

Експертна система (ЕС), насамперед, є програмним продуктом, і її призначення – автоматизація

діяльності людини. Однак принциповою відмінністю ЕС від інших програм є те, що вона виступає не в ролі «асистента», що виконує за людину частину роботи, а в ролі «компетентного партнера» – експерта-консультанта в будь-якій конкретній предметній області. ЕС акумулюють у собі і тиражують досвід і знання висококваліфікованих фахівців, дозволяють користуватися цими знаннями користувачам «неспеціалістам» в даній предметній області. Тому ЕС не замінюють собою експерта в його діяльності, а, навпаки, розширюють можливу сферу застосування знань авторитетних фахівців. Крім того, здатності ЕС вирішувати поставлені перед ними завдання не зменшуються з часом і не забуваються при відсутності практики, легко поширюються, так як є комп'ютерною програмою, прекрасно документовані, при багаторазовому вирішенні однієї і тієї ж задачі ЕС видають одне і теж рішення на відміну від людини, яка піддається емоційним факторам, експлуатація ЕС значно дешевше, ніж оплата праці людини-експерта.

Таким чином, призначенням експертних систем є консультування з вузькоспеціальних питань при прийнятті рішень людиною, для посилення і розширення професійних можливостей її користувачів.

Традиційними галузями застосування експертних систем є наступні: інтерпретація даних, діагностика, моніторинг, проектування, прогнозування, планування, навчання.

Існують певні технології розробки ЕС, що складаються з таких шести етапів: ідентифікація, концептуалізація, формалізація, реалізація, тестування і дослідно-експериментальна експлуатація. На етапі ідентифікації визначаються задачі, які підлягають розв’язанню, виявляються проміжні цілі розробки, визначаються експерти за напрямом і типи користувачів. Етап концептуалізації призначений для змістовного аналізу проблемної області, виявлення наявної інформації та визначення множини альтернативних методів розв’язання поставлених задач. На етапі формалізації обирається інструментарій і визначаються способи зберігання та представлення всіх типів знань, формалізуються основні поняття, визначаються способи інтерпретації знань, моделюється робота системи, оцінюється адекватність понять, методів розв’язання, засобів подання і маніпулювання знаннями. На етапі виконання здійснюється наповнення експертом бази знань.

Експертна система - це програмний засіб, що використовує експертні знання для забезпечення високоефективного рішення неформалізованих задач у вузькій предметній області [2]. Основу ЕС складає база знань (БЗ) про предметну область, що накопичується в процесі побудови й експлуатації ЕС. На рис. 1 зображені основні властивості ЕС.

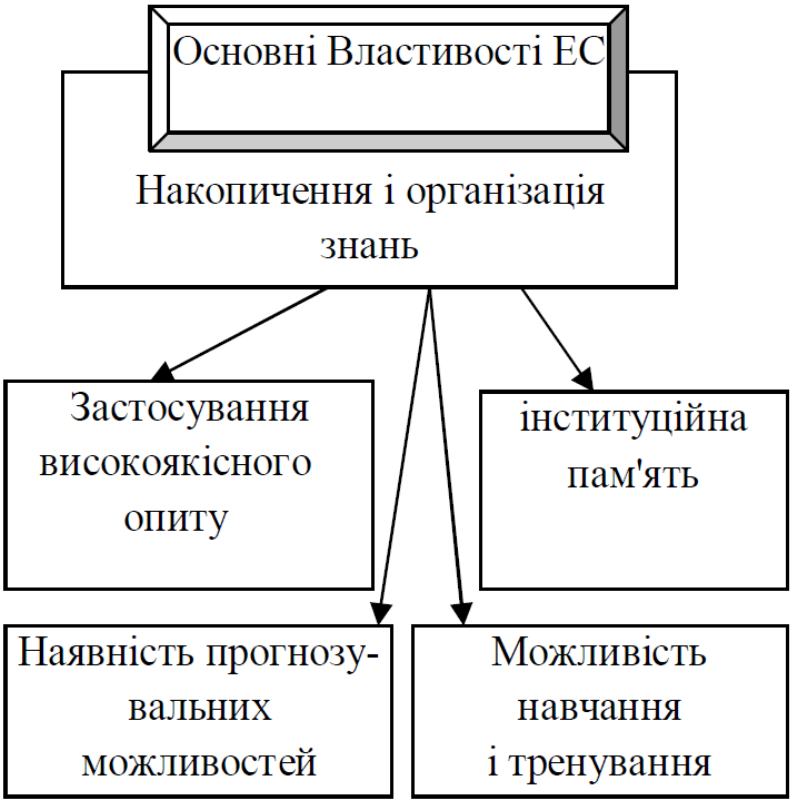

Рис. 1. Основні властивості експертних систем

Властивості ЕС:

1). Застосування для рішення проблем високоякісного досвіду, який представляється рівнем мислення найбільш кваліфікованих експертів у даній області, що веде до творчих, точних та ефективних рішень.

2). Наявність прогностичних можливостей, тобто використання принципу «If… Then… Else…». Це означає, що системи можуть видавати відповіді на поведінку в конкретній ситуації і показувати, як зміняться ці відповіді у нових ситуаціях [3]. Це дасть змогу користувачу оцінити можливий вплив нових фактів або інформації та зрозуміти, як вони пов'язані з рішенням.

3). Забезпечення такої нової якості як інституціональна пам'ять за рахунок бази знань, що входить до складу ЕС (експерти можуть з часом змінюватися, а їх досвід залишається).

4). Можливість використовування ЕС для навчання та тренування спеціалістів і робітників, забезпечуючи їх великим багажем досвіду і стратегій.

У розробці й експлуатації експертної системи беруть участь такі фахівці:

✓ Експерт – висококваліфікований фахівець у проблемній області, задачі якої повинна вирішувати експертна система, який визначає знання, що характеризують проблемну область, забезпечує повноту і правильність введених в систему знань.

✓ Інженер зі знань (когнітолог) – фахівець з розробки експертних систем, який виступає в ролі проміжного буфера між експертом і базою знань. Він допомагає експерту виявити і структурувати знання, необхідні для роботи експертної системи, здійснює вибір інструментального засобу, що найбільше підходить для даної проблемної області, визначає спосіб подання знань у цьому інструментальному засобі.

✓ Програміст – фахівець з розробки інструментальних засобів, що здійснює їхнє створення і сполучення з тим середовищем, у якому вони будуть використовуватися.

✓ Користувач – людина, що використовує вже побудовану експертну систему.

Взаємозв'язки основних учасників побудови та експлуатації експертної системи наведені на рис. 2.

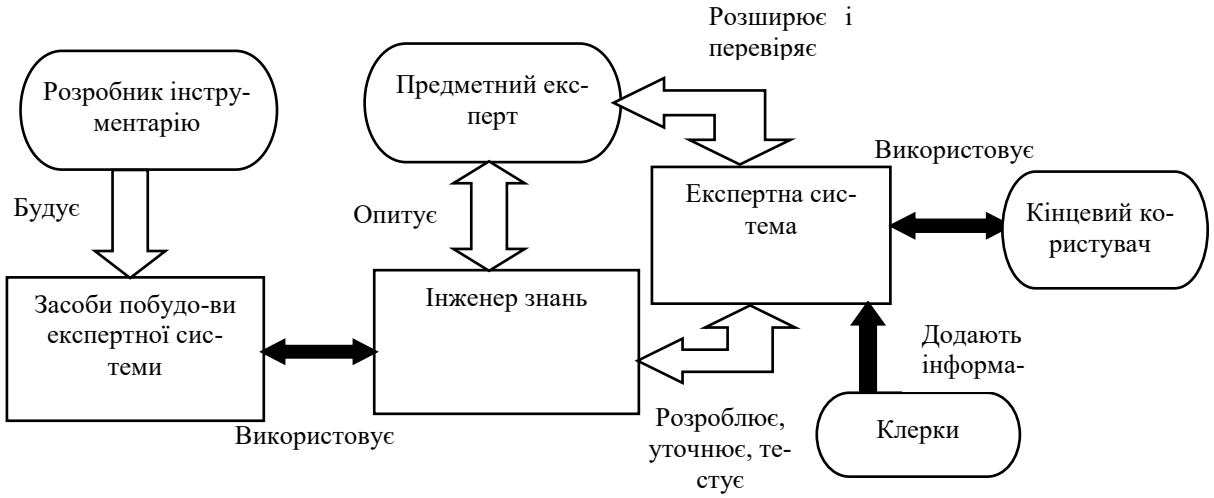

Рис. 2. Взаємозв'язки основних учасників побудови та експлуатації експертної системи

Експертна система (рис. 2) містить такі основні компоненти, як: машина логічного виведення (вирішувач, інтерпретатор правил), база знань, підсистема набуття знань, підсистема пояснення рішень, інтерфейсна підсистема (діалоговий компонент), робоча пам'ять (база даних).

База знань – найбільш цінний компонент ядра ЕС, що містить сукупність знань про предметну область і способи вирішення задач, які записані у формі, зрозумілій неспеціалістам в програмуванні: експерту, користувачеві. У базі знань зберігаються довгострокові знання, що описують предметну область у вигляді загальних фактів (фраз без умов, що містять твердження, які завжди є абсолютно вірними) і правил (тверджень, істинність яких залежить від деяких умов, що утворюють тіло правила, які описують доцільні перетворення фактів цієї області з метою породження нових фактів або гіпотез.

Робоча пам'ять (база даних) – призначена для збереження вихідних даних (фактів, що описують поточну ситуацію).

Машина логічного виведення (вирішувач) – основна частина експертної системи, яка, використовуючи інформацію з бази знань генерує рекомендації з вирішення задачі та містить інтерпретатор, диспетчер і робочий список правил).

Оболонка експертної системи – програма, що забезпечує взаємодію між базою знань та машиною логічного виведення. Користувач взаємодіє з оболонкою через інтерфейсну підсистему, передаючи їй запити. Остання активізує машину логічного виведення, яка звертається до бази знань, вибирає в ній і генерує в процесі логічного виведення знання, необхідні для відповіді на конкретне питання, і передає сформовану відповідь користувачу або як рішення проблеми, або у формі рекомендації чи поради.

Інтерфейсна підсистема організує взаємодію користувача і експертної системи в процесі вирішення задачі за допомогою перетворення запитів користувача у внутрішню мову подання знань експертної системи і навпаки.

Підсистема набуття знань – автоматизує процес наповнення експертної системи знаннями експертом або інженером зі знань через редактор бази знань.

Підсистема пояснень – дозволяє контролювати хід суджень експертної системи і пояснювати її рішення або їхню відсутність з вказівкою використаних знань.

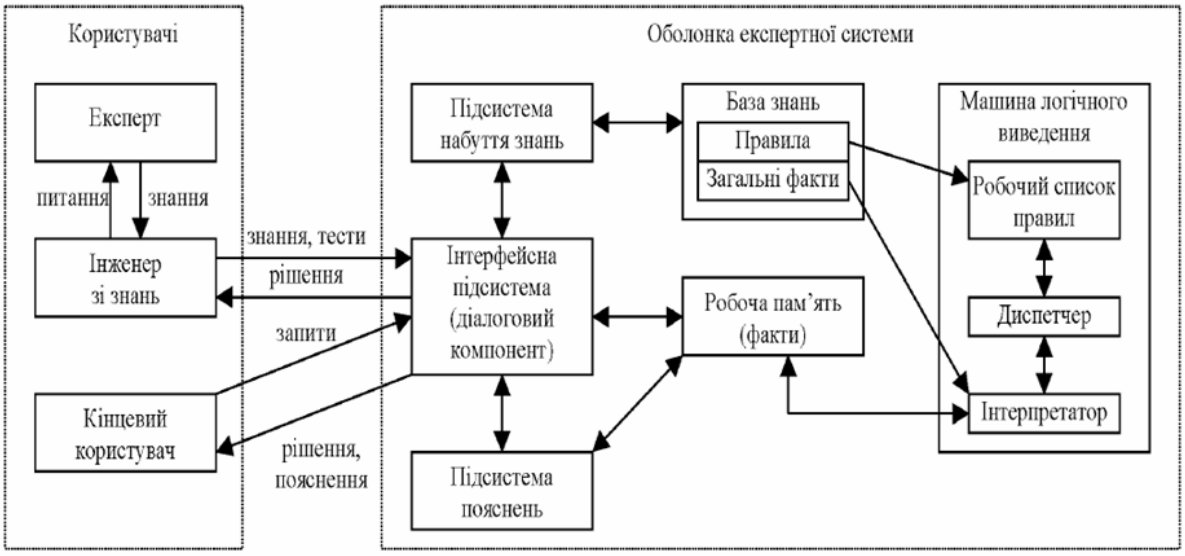

Рис. 3. Схема ідеальної статичної експертної системи

Аксіоматичне формування експертної системи:

$$ES_{ia}^{ja}\left(i \in I,\ j \in J\right), k \in K, a \in A \qquad (1)$$

Повністю визначається парою (Da, ξa), де

$$D_a = \left(DB_{ia}^{jk}, KB_{ia}^{jk}, CB_{ia}^{jk}\right) \qquad (2)$$

де DB_{ia}^{jk} – база даних, KB_{ia}^{jk} – база знань, CB_{ia}^{jk} – зв'язуючи правила.

Однією з найбільш важливих проблем, характерних для систем, заснованих на знаннях, є проблема подання знань. Типовими моделями подання знань є:

• логічна модель;

• модель, заснована на використанні правил (продукційна модель);

• модель, заснована на використанні фреймів;

• модель семантичної мережі.

Представлення знань у вигляді продукцій найбільш поширене в експертних системах, так як запис знань фактично ведеться на підмножині природної мови. Наслідком цього є те, що правила легко читаються, їх просто зрозуміти і модифікувати, експерти можуть без проблем сформулювати нове правило або вказати на помилковість якого-небудь існуючого.

В якості умови і дії в правилах може бути, наприклад, припущення про наявність тієї чи іншої властивості, що приймає значення істина або неправда. При цьому терміни дії слід трактувати широко: це може бути як директива до виконання будь-якої операції, рекомендація, або модифікація бази знань – припущення про наявність якого-небудь похідного властивості.

При використанні продукційної моделі база знань складається з набору правил. Знання представлені у вигляді речень (продукцій) типу: If *(умова)* - Then *(дія)»*.

Під умовою розуміється деяке речення-зразок, за яким здійснюється пошук у базі знань, а під дією – дії, що виконуються при успішному результаті пошуку. Як в умові, так і у дії правила можуть враховувати декілька виразів, що об'єднані логічними зв'язками AND, OR, NOT.

Результати роботи експертної системи доступні користувачеві через діалоговий інтерфейс. Він за необхідності дозволяє ознайомитися з ходом логічних міркувань системи що призводить до отримання даного результату.

Для того, щоб ЕС змогла швидко і якісно пояснювати правильність своїх відповідей, а також доцільність поставлених запитань, вона записує в робочій пам'яті хід своїх міркувань та їх послідовність. Факт можливості дістати пояснення надає користувачу ілюзію, ніби-то система перевіряє відповідність правил, що записані в базі знань. Між тим ЕС пояснює свої дії виключно лише видаючи інформацію про хід процесу міркувань. В ЕС продукційного типу пояснення записуються в базу знань за допомогою модифікованого правила продукції:

Правило XXX ЯКЩО < умова >

ТО < висновок чи дія >

ТОМУ ЩО < обґрунтування >

Обґрунтування – це текст, що його дістане користувач після використання даного правила, маючи намір дістати пояснення.

Висновок. Особливості ЕС полягають у тім, що вони повинні володіти:

1. Компетентністю, а саме:

– досягати експертного рівня рішень (тобто в конкретній предметній області мати той же рівень професіоналізму, що й експерти-люди);

– мати активну працездатність (тобто застосовувати знання ефективно і швидко, уникаючи, як і люди, непотрібних обчислень);

– мати адекватну працездатність (тобто здатність лише поступово знижувати якість роботи з міри наближення до границь діапазону компетентності або припустимої надійності даних).

2. Можливістю до символьних міркувань, а саме:

– представляти знання в символьному вигляді;

– переформулювати символьні знання. На жаргоні штучного інтелекту символ – це рядок знаків, що відповідає змісту деякого поняття. Символи поєднують, щоб виразити відносини між ними. Коли відносини представлені в ЕС вони називаються символьними структурами.

3. Глибиною, а саме:

– працювати в предметній області, що містить важкі задачі;

– використовувати складні правила (тобто використовувати або складні конструкції правил, або велику їх кількість);

4. Самосвідомістю, а саме:

– досліджувати свої міркування (тобто перевіряти їхня правильність);

– пояснювати свої дії.

Таким чином перевагою експертних систем є те, що вони, використовуючи декларативні бази даних, а також продукційні правила, відносини, прототипи, схеми і семантичні мережі, для уявлення і використовування знань, що містяться в них, відкривають дійсно новий підхід до програмування, який полягає в можливості передачі від людини до програми найпростішим чином знань неврегульованої структури в довільних областях.

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