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Article



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## COMPARATIVE ADVANTAGE AND AGRICULTURAL TRANSFORMATION IN TOGO: EVIDENCE FROM GLOBAL, AFRICAN, AND CHINA-ORIENTED COMPARISONS

**Abstract:** Togo remains a predominantly agrarian economy in which agriculture contributes a large share of output and employment, yet the sector continues to exhibit low productivity, weak resilience, and limited integration into higher value-added segments of the food system. Based on the comparative advantage framework, this article condenses a broader thesis into a journal-style study by comparing Togo's agricultural development with the world average, selected African countries, and China during 2017-2021. Drawing primarily on FAO and World Bank indicators, the paper examines agricultural structure, crop yields, mechanization, irrigation, food supply, fertilizer use, greenhouse gas emissions, processing value added, rural electrification, and trade patterns. The results show that Togo possesses clear natural and labor-based comparative advantages in tropical and cash-crop agriculture, but these advantages remain only partially converted into competitive strength because of extremely low mechanization, very limited irrigation, inadequate processing capacity, weak extension systems, and infrastructure bottlenecks. Relative to the global average, Togo performs especially poorly in machinery power per hectare, irrigation coverage, and agricultural value added per worker. Relative to leading African peers, Togo shows excessive dependence on primary agriculture and insufficient agro-processing. In contrast with China, the comparison highlights major gaps in grain productivity, rural electrification, technical upgrading, and organizational capacity. The study argues that Togo should not attempt to replicate high-input models mechanically. Instead, it should pursue an adaptive pathway built on smallholder-compatible mechanization, water-saving irrigation, climate-smart agriculture, agro-processing, and selective international cooperation. China's experience is particularly relevant in technology diffusion, rural infrastructure, and the coupling of food security with ecological modernization. The article concludes with policy recommendations for transforming Togo's resource endowments into dynamic comparative advantages.

**Key words:** Togo; comparative advantage; agricultural transformation; China-Africa cooperation; agricultural modernization.

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### 1. Introduction

Agriculture remains the material foundation of economic and social development in many low-income countries, and this is especially true in Togo. The country's climate and topography provide conditions suitable for diverse agricultural activities, ranging from food crop cultivation to cash crop production. At the same time, Togo continues to face

structural weaknesses common to many agrarian economies in sub-Saharan Africa: low labor productivity, heavy dependence on rainfall, weak rural infrastructure, and limited processing capacity. These constraints affect not only food security and rural incomes, but also the country's ability to participate effectively in regional and global agricultural value chains.

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The original thesis on which this article is based approached these issues from the perspective of comparative advantage. That perspective remains useful because it emphasizes that development is not simply a matter of producing more, but of identifying those areas in which a country can deploy its resource endowments most efficiently while progressively upgrading technology, institutions, and market organization. For Togo, the central question is not whether agriculture should remain important, but how agriculture can move from a low-productivity, vulnerability-prone sector to a modernized and value-adding engine of development.

To answer this question, the present paper reconstructs the thesis into a concise journal article using a three-level comparative framework. First, Togo is compared with the world average in order to identify its broad structural deficits. Second, it is compared with African peers to reveal its position within the regional agricultural landscape. Third, it is compared with China to explore how an agrarian country can move toward higher productivity, infrastructure coverage, and technological upgrading. China is not treated as a model to be copied wholesale. Rather, it serves as a reference case demonstrating how policy coordination, infrastructure, science and technology, and institutional innovation can gradually transform agricultural comparative advantage.

The paper makes two contributions. Empirically, it synthesizes multi-source indicators for 2017-2021 into a compact comparative diagnosis of Togo's agricultural development. Analytically, it argues that Togo's comparative advantage is currently static and resource-based, whereas successful transformation requires converting natural endowments into dynamic comparative advantage through technology, organization, and value-chain upgrading.

## 2. Literature Review and Analytical Framework

Existing studies on Togo's agriculture focus mainly on three themes. The first concerns agricultural efficiency and climate vulnerability. Research shows that drought, rainfall instability, soil degradation, and low input efficiency are major constraints on crop performance and household welfare (Mikémina, 2019; Boansi, 2017). The second theme concerns policy and adaptation strategies. Studies emphasize climate-smart agriculture, irrigation, improved seed adoption, fertilizer policies, and public agricultural investment as major channels for raising output and reducing food insecurity (Affoh et al., 2022; Ali, 2022; Yovo & Ganiyou, 2023). The third theme concerns cooperation and organizational arrangements, including cooperatives, regional trade integration, and international assistance, especially from multilateral organizations and China (Berge et al., 2021; Mensah, 2011).

However, several gaps remain. Much of the literature is problem-specific, focusing on fertilizers, climate adaptation, or cash crops in isolation. There is less work that situates Togo's agriculture within a broader comparative structure linking the global, African, and national levels. In addition, the distinction between natural comparative advantage and competitive advantage built through technology and institutions is often insufficiently developed. A country may possess favorable climate and labor conditions but still fail to realize strong agricultural performance when infrastructure and market systems remain weak.

This article therefore uses comparative advantage as an organizing framework rather than as a narrow trade model. In its classical sense, comparative advantage refers to relative efficiency in production. In development practice, however, comparative advantage is dynamic: it depends not only on land, labor, and climate, but also on irrigation, extension, transport, energy access, processing facilities, standards, and policy capacity. The same tropical conditions that favor cash crops may yield very different outcomes depending on whether farmers have access to improved seed, mechanization services, storage, roads, and markets.

Accordingly, this paper interprets agricultural transformation in Togo as a process of moving from static comparative advantage based on natural endowments toward dynamic comparative advantage based on productivity, resilience, and value addition. The global comparison identifies absolute gaps; the African comparison identifies relative regional positioning; and the China comparison offers a development trajectory emphasizing technical change, infrastructure, and policy learning.

## 3. Data and Method

This article is a condensed comparative study derived from the uploaded thesis. It relies primarily on secondary data from the Food and Agriculture Organization of the United Nations and the World Bank, complemented by the thesis's synthesis of related literature. The observation window is 2017-2021, a period that captures pre-pandemic conditions, the shock of COVID-19, and the early recovery phase.

The analysis focuses on six dimensions. First, it examines the structural position of agriculture through rural population, agricultural employment, land use, and agriculture's share in GDP. Second, it evaluates production performance through crop and livestock indices, per capita food supply, and selected crop yields. Third, it assesses modernization capacity using machinery power per hectare, fertilizer use, irrigation coverage, and rural electrification. Fourth, it considers value-chain upgrading through agricultural processing value added and trade patterns. Fifth, it discusses environmental sustainability through fertilizer trends and agricultural greenhouse gas emissions. Sixth, it

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uses comparative reading of China's experience to identify potentially transferable elements for Togo.

The study is not intended to estimate causal effects econometrically. Instead, it uses comparative descriptive analysis to identify patterns, bottlenecks, and policy implications. This is appropriate for a condensed journal article adapted from a broader thesis whose main purpose was diagnostic and strategic rather than strictly econometric.

### 4. Results

#### 4.1 Togo's agricultural profile: strong dependence, weak modernization

Between 2017 and 2021, agriculture remained central to Togo's social and economic structure. The rural population remained larger than the urban population, although the urban share rose gradually. Agriculture still employed a substantial proportion of the labor force, and agricultural land accounted for more than 90% of land use throughout the period. These features confirm that Togo remains an agriculture-led economy in structural terms.

At the same time, the production data reveal only modest progress. Food and crop production indices trended upward overall, but growth was not rapid. Livestock output fluctuated more sharply, falling in 2020 before recovering in 2021. Per capita food supply also showed instability, especially around the pandemic period, reflecting the vulnerability of the agricultural system to external shocks. Trade data indicate that Togo continues to export agricultural raw materials while importing relatively little agricultural raw material as a share of total merchandise imports. This pattern is consistent with a primary-product export structure that generates foreign exchange but captures only limited value added domestically.

The modernization indicators show the deeper problem. Fertilizer use rose and then fell, suggesting both cost pressures and a partial shift toward greener practices, but without a corresponding technological leap in productivity. Rural electricity coverage remained around one-fifth of the rural population, indicating severe energy constraints. Agricultural greenhouse gas emissions, particularly methane and nitrous oxide, increased during most of the period, showing that low-productivity agriculture is not automatically low-impact. In short, Togo's agriculture remains extensive rather than intensive: it occupies much land and labor, but generates limited productivity and limited value-chain upgrading.

#### 4.2 Togo versus the world average: large structural gaps

The global comparison highlights the scale of Togo's developmental lag. Per capita agricultural value added in Togo grew only slightly, from roughly US\$892 to US\$925 during 2017-2021, while the global average remained around US\$3,000. This means that Togo's agricultural labor generates only a

fraction of world-average value. The underlying reasons are visible in the factor and infrastructure indicators.

First, agricultural mechanization is extremely low. The thesis reports machinery power of only 0.024-0.029 kilowatts per hectare in Togo, compared with about 0.68 kilowatts per hectare globally. This gap is not marginal; it signals a production system still heavily dependent on manual labor and animal traction. Second, irrigation coverage rose only from 1.8% to 2.3%, far below the global average of more than 20%. In practical terms, this means that most Togolese farming remains rainfall dependent and therefore highly exposed to climatic variability. Third, crop yields remain below world averages. For maize, Togo's yield ranged from about 1.05 to 1.23 tons per hectare, compared with a global range of roughly 1.65 to 1.75 tons per hectare. Togo therefore achieves only around 60%-70% of the world average in this key staple.

These gaps matter because they interact. Low mechanization makes timely land preparation difficult. Weak irrigation reduces resilience to rainfall shocks. Limited rural electricity raises the cost of storage, processing, and pumping. Weak extension and input systems further prevent farmers from using seed, fertilizer, and pest-control technologies efficiently. As a result, Togo's natural comparative advantage in tropical agriculture is not converted into high productivity or stable supply.

#### 4.3 Togo within Africa: high agricultural dependence, low value addition

Compared with selected African countries, Togo presents a paradox: agriculture's share in GDP is high, yet the sector's productivity and processing depth remain low. During 2017-2021, agriculture contributed roughly 38%-40% of Togo's GDP, well above the broader African average. This does not necessarily indicate superior performance. Rather, it reflects the relatively slow development of industry and services, so that agriculture carries a heavier burden in output and employment.

Agricultural labor productivity in Togo remained around US\$890-US\$910, below the level achieved in stronger African agricultural economies and far below countries that have combined irrigation, market integration, and agro-processing. The thesis also reports that the value-added rate of agricultural processing in Togo remained around 18%, while cashew processing stayed below 5%. This is a major bottleneck. Exporting raw products rather than processed goods means that value, employment, and learning opportunities are captured elsewhere.

The regional comparison is particularly instructive because it shows that agricultural dependence alone does not generate transformation. Countries that have upgraded processing, logistics, standards, or horticultural exports have moved further

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into higher value-added segments. Togo’s challenge is therefore not simply to produce more crops, but to build the intermediate systems that connect farm output to storage, processing, branding, and regional markets.

#### 4.4 Togo and China: from static endowments to dynamic advantage

The comparison with China illustrates what long-term agricultural transformation can look like when technological change, infrastructure, and state capacity reinforce one another. From 2017 to 2021, China’s rural population continued to decline while urbanization advanced, yet grain and crop production remained strong. Major staple yields were much higher than in Togo: maize yields were around 6 tons per hectare, cassava yields exceeded 16 tons per hectare, rice yields rose from about 6.9 to 7.1 tons per hectare, and sorghum yields were around 4.76 tons per hectare. Rural electrification effectively reached universal coverage.

China also reduced fertilizer consumption while sustaining production growth, indicating gains in

efficiency rather than simple input intensification. Agricultural greenhouse gas emissions trended downward over the period, reflecting the diffusion of water-saving irrigation, manure utilization, straw return, and climate-smart techniques. None of these outcomes emerged automatically from natural endowments alone. They were the product of long-term investment in research, extension, rural power systems, irrigation works, and coordinated policy support.

For Togo, the China comparison does not imply that large-scale mechanized farming should be copied directly. Farm size, fiscal capacity, and ecological conditions differ sharply. The real lesson is institutional and strategic. China’s experience shows the importance of treating agricultural modernization as a systems project: improving seed, equipment, water, energy, roads, extension, and processing together rather than separately. It also demonstrates that ecological goals and productivity growth need not be contradictory if technological upgrading is well designed.

**Table 1. Selected comparative indicators reported in the thesis**

Indicator	Togo	Comparator	Implication
Agricultural mechanization (kW/ha, 2017-2021)	0.024-0.029	World: about 0.68	Severe machinery deficit
Irrigation coverage	1.8%-2.3%	World: above 20%	High exposure to rainfall shocks
Maize yield (t/ha)	1.05-1.23	World: 1.65-1.75; China: about 6.0	Large productivity gap
Agricultural GDP share	About 38%-40%	Africa average markedly lower	Heavy reliance on primary agriculture
Agricultural labor productivity	About US\$890-US\$910	Higher in stronger African peers	Low value creation per worker
Rural electrification	Around 20%	China: universal coverage	Energy bottleneck for storage and processing

*Note: Values are condensed from the uploaded thesis and its FAO/World Bank-based comparative analysis.*

#### 5. Discussion

The comparative evidence suggests that Togo’s agricultural challenge is not the absence of comparative advantage, but the weakness of the mechanisms through which comparative advantage is realized. Togo already has favorable climatic conditions for tropical crops and a large agricultural labor base. It also retains ecological potential for relatively green development. Yet these strengths remain static. Without irrigation, electrification, mechanization services, and value-chain organization, they do not generate high or stable returns.

Three implications follow. First, Togo should prioritize smallholder-compatible modernization. Large imported machinery is often unsuitable for fragmented plots, but shared service platforms, rental systems, and modular equipment can raise labor productivity without requiring complete land consolidation. Second, irrigation must be treated as a strategic threshold variable. Even modest expansion of water control through low-cost pumps, solar systems, and community schemes could substantially improve resilience, especially under increasing climate uncertainty. Third, agro-processing should become a core development priority. The country

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cannot rely indefinitely on exporting raw cashew, cotton, coffee, and other primary materials while importing higher value-added goods.

International cooperation can support this transition if it is selective and capacity oriented. Multilateral institutions can assist with irrigation, seed systems, and resilience financing. Regional African integration can help enlarge markets and lower cross-border trade frictions. China can provide relevant experience in rural infrastructure, small machinery, demonstration agriculture, and the combination of food security with green development. The key is to avoid dependency on project-based transfers that do not build local capabilities. What Togo needs most is a gradual accumulation of domestic technical, organizational, and policy capacity.

### 6. Policy Recommendations

Based on the comparative results, four policy directions are especially important.

First, strengthen agricultural science, technology, and extension. Togo should increase support for adaptive research on drought-resistant seed, soil improvement, crop protection, and local mechanization needs. Demonstration zones and farmer training platforms should be linked to real production constraints rather than operating as isolated showcase projects.

Second, expand small-scale irrigation and rural energy access. Water-saving irrigation, solar pumps, on-farm storage, and rural electrification would jointly improve production stability, post-harvest management, and processing possibilities. Given fiscal limits, interventions should focus first on zones with clear yield and market potential.

Third, develop agro-processing and value chains for selected products. Cashew, cassava, cotton, coffee, and other priority commodities should be connected

to storage, grading, packaging, and processing clusters. The objective is not only export growth, but also higher domestic value retention and job creation.

Fourth, promote green and climate-smart transformation. Togo's modernization path should not replicate environmentally costly high-input models. Efficient fertilizer use, integrated soil management, crop diversification, and low-emission livestock practices can support both resilience and productivity.

### 7. Conclusion

This article condenses a broader thesis into a journal-style comparative analysis of Togo's agriculture. The evidence from 2017-2021 shows that Togo remains heavily dependent on agriculture but has not yet translated its resource endowments into dynamic comparative advantage. Relative to the world average, Togo exhibits pronounced deficits in mechanization, irrigation, and labor productivity. Relative to stronger African peers, it suffers from weak agro-processing and continued reliance on primary production. Relative to China, it lags far behind in infrastructure, technology diffusion, and organizational capacity.

Even so, the diagnosis is not pessimistic. Togo possesses a real basis for agricultural transformation: suitable agro-climatic conditions, labor availability, and opportunities for selective upgrading in both food crops and cash crops. The central task is to connect these endowments to irrigation, energy, extension, processing, and market systems. Comparative advantage should therefore be understood not as a fixed gift of nature, but as a developmental process. When supported by appropriate institutions and international cooperation, Togo can move from vulnerable subsistence-oriented agriculture toward a more productive, resilient, and value-adding agricultural economy.

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## THE ARTISTIC SYMBOLISM OF THE CANDLE AND THE MOTH (in the work of Alisher Navoi as in example)

**Abstract:** This article discusses the images of a candle and the moth in the works of the thinker poet Alisher Navoi, in particular in his work "Lison ut-tair", and examines their meaning. The images of the candle and the moth are associated with Mansur Halloj. The essence of these images are and their mystical meanings analyzed. The article also closely analyzes Navoi's verses. The moth's desire toward to candle and its burning in the flame are analyzed as a symbol of a true lover. In classical Eastern literature, the moth is considered superior to the nightingale. The article further analyzes a narrative presented in the epic "Lison ut-tayr", focusing on the images of a candle and the moth whithin it.

**Key words:** candle, moth, image, sufism, spiritual seeker, shabistan, divine unity, love.

**Language:** English

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### Introduction

One of the most frequently used figurative images in classical Eastern literature. The burning of the candle is compared to the radiant face and graceful stature of the beloved, and the constant pursuit of the moth for him is compared to true love. According to Sufi terminology, it is explained as follows: "A candle is a wax, a torch. Divine light. The manifestation of the divine light that ignited the heart of the righteous, the divine light that shone in the hearts of those who observe it." Indeed, in Sufi literature, the image of the candle is a divine light, a source, and the moth is a symbol of the realization of the divine essence - the source, and it ultimately perishes (mortal) on the way to its goal (by throwing itself into the fire).

Using these symbols, which are among the most prolific images in Navoi's lyrics and epics, the poet also evaluates the situation of the moth reaching the candle as a phenomenon, and in this case, he reveals a mystical idea such as the two benefits of the moth. The

reason for this should be sought in the essence of Navoi's ideological direction - Naqshbandiyyah. Expressing his opinion on the direction of this order, prof. N. Kamilov writes the following: "Naqshband directed his attention toward reconciling sufism with Sharia, to extinguish the excitement and ardor of inspiration, to call out "Anal-Haq" like Mansur, to create a million mangals instead of blazing flames, and to prefer the moth that quietly strives for a candle, not the restless nightingale".

### The results and discussion

Yes, Navoi also compares the moth to the spiritual seeker, which favors a quiet inclination - sahv, and creates beautiful poetic works by sometimes paralleling and sometimes contrasting the nightingale, which "whispers and struggles" in love, with the symbol of the shirker, which he creates beautiful poetic devices:

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*Gul yuzida bulbul sening asroringa notiq,  
Sham' o'tida parvona sening husninga shaydo.*

\*\*\*

*Jamoling partavidin sham' o'ti gar gulsiton  
etmas,  
Nedin parvona o't ichra o'zin solur Xaliloso.*

It seems that the candle and the moth hold a special significance, and through these symbols, beautiful similes and meaningful lines have been created. Moreover, depending on the poet's skill, they were useful in various meanings, especially in describing the beauty of the Beloved and the state of the lover:

*Ochqil o'tlug' orazing, ey sham'kim,  
parvonadek  
O'rtanay boshing uza bir necha qatla aylanib.*

The lyrical hero addresses his lover as "O candle, who is it?" and tells him to open his face in the meadow. The lover thus says that he wants to circle his lover's head several times, like a moth burning in the flame of a candle, and to be reconciled. It seems that the poet cannot imagine love without such reconciliation and suffering.

In another verse, the poet sings that just as the beloved's beauty illuminates a ruined hut, every moth that burns also kindles and brightens the candle of love:

*Ul charog'i husn vayron kulbani yorutqali  
Mehr sham'in yorituptur har kuyuk parvonamiz.*

In Navoi's work, the interpretation of the candle and the Shabistan has a deeper meaning:

*Ul malohat sham'idin mundog'ki jismim  
yonadur,  
Har bir uchqun g'am shabistonida bir  
parvonadur.*

The lover's body is said to burn due to the candle of the lover's lover, and each spark that flies from it is compared to a moth on a night of sorrow. In this, the sparks from the burning body are likened to moths, further enhancing the artistic quality of the verse. In another verse, the poet uses the terms candle and shabestan together:

*Pardag'a kirgan kebi xurshidi raxshon har  
kecha,  
Azmi xilvat aylar ul sham'i shabiston har kecha.*

When Navoi, alongside these symbols, turns to address the heavens (*gardun*), the mood of the poem takes on a different tone. *Don't learn from the beauty of others, for every night, the light of a thousand candles will not burn a single moth.* Because,

according to the poet, one should not be inspired by the beauty of others. After all, even if thousands of candles (stars) light up the sky every night, none of them can burn a moth, just as the beauty of others cannot burn the heart of a lover. For example, when Navoi talks about the moth burning brightly from the beauty of Mahbuba, he emphasizes the eternal truth that the fate of love is to burn like a moth:

*Lam'ai ruxsoridin parvonadek kuysam ne tong  
Menki, yillar ul malohat sham'i sargardonimen.*

Indeed, Parva is a lover, a symbol of immortality and monotheism. The candle is the soul of Arif. The beloved. Like his predecessors, Navoi used these images to describe divine love. The candle is described as divine love, the beauty of Allah, while the moth is embodied as the seeker of this love, the servant. The burning of a lover who sees his beloved is like the burning of a parva when he sees a candle:

*Keldimu ko'r dum yuzin qayturmen emdi  
o'rtanib,  
Sham'ni ko'rgan nafas yonmoq kerak  
parvonag'a.*

The symbol of the candle in Navoi's poetry plays an important role in interpreting the moral, secular and mystical essence of love. After all, love is not always a matter of whimpering, but those who see "the solitude of the gathering" have inner enlightenment, a special burning passion on the path of discovery, and a special selfless determination. The meaning of this verse confirms the ideas we have expressed regarding the candle and the moth:

*Ul o'tki o'rtadi parvonani, hamul o'tdin  
Ko'ringki qovruladur sham' dog'i yog'i bila.*

It becomes clear that the discussion centers on the love of the moth; that is, the poet compares the lamenting love of the nightingale with the silent yet body-consuming 'wordless' love of the moth. There is the candle, and around it a tiny moth striving toward the flame. It is drawn to the fire with such devotion and intensity that it finds no rest until it merges with the flame and burns away. Yet, despite the depth of its love and the (intensity) of its pain, the moth does not cry out or lament; rather, it quietly and silently continues its movement toward the fire. That 'fire,' the flame of divine love, burns not only the moth but also the candle itself—melting and consuming it along with its wax and oil. Through these allegories, the great poet seeks to convey to us the boundless power of Love—its force that encompasses all particles and living beings, both lover and beloved alike. The candle's flame symbolizes divine love; its wax and oil represent the world and the human body; and the moth stands as the symbol of the loving human being. The

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moth is a symbol of *fana*—that is, the path of freeing oneself from base qualities, acquiring noble virtues, and abandoning worldly desires. This is the path of humble dervishes and the friends of God.

In the maqta of the poet's famous ghazal beginning with 'Qaro ko'zum, kelu...', it can be seen that the meaning attributed to the image of the candle becomes even more profound and weighty.

*Navoiy, anjumani shavq jon aro tuzsang,  
Aning boshopik o'qin sham'i anjuman qilg'il.*

Anjumani shavq - the poet expressed the surge of passion and desire in the heart of a lover, the desire to reach the beloved with this expression (the lexical meaning of the expression is a dream, a meeting of strong passion, a gathering). This also implies spiritual excitement, agitation, the beginning of a storm of joy. Creating such an assembly in the soul is the heart's desire for bright dreams. 'Boshopik' o'q' refers to a sharp-pointed arrow, a keen-tipped shaft; the resemblance of the arrowhead to a grain spike is also taken into account. In this form, it is visually akin to a beautiful eyelash and a burning candle. In fact, by 'boshopik' o'q,' Navoi refers to the Beloved's eyelash, for the eyelash is the arrow of love—one that pierces straight into the heart.

The content of the couplet: "O Navoi, if you want to create a passionate and exciting gathering in your soul, make your beloved's eyelashes—the arrow—the candle of this gathering." Here, the literary art of couplet 2 is reproduced through new details, that is, the eyelashes also resemble the letter alif, and its being the candle of the gathering between the soul means that it is placed like an alif in the middle of the soul. In this way, the great poet was able to show amazing skill by comparing five things to each other at once. There is also the following mystical meaning in this: the eyelashes—the arrow—are a symbol of divine inspiration and revelation that illuminates the heart of the eyelashes when they are filled with the same passion as the state of the state of the state. "The passion of the gathering" in this context means rising to the state of the state. In conclusion, the conclusion of the verse is that the lover's desire for his beloved is an endless dream, a striving for an unattainable ideal. After all, moral purification and love for this purity are feelings that continue to burn in the heart of a true person. When the dream of seeing your beloved occupies your heart, oppresses it, and overflows, turn its eyelashes into the lamp of this dream's culmination, and illuminate your heart with the candle of its love, says the poet. Because a heart that is caught in the arrow of love's pain will always be burning, a torch.

In one instance, Navoi compares his teacher and friend, Sayyid Hasan, to a candle. In reality, he was an ordinary man—a soldier by profession—who, at the end of his life, donned the dervish's cloak and sat in a khanaqah. But, in Navoi's eyes, he was one of the

great figures of his time.

*Safo subhining mehri purxandasi,  
Fano shomining sham'i raxshandasi,*

In general, it is difficult to find a poet's divan in which these images do not participate, and there are also a number of parables, discussions and epics whose main characters are these images. For example, the parable "Parvonalar majmu'i sham' haqiqi sharida" (or, to put it more simply, "Sham' and parvonalar") in Navoi's epic "Lison ut-tair" is also one of the works of this type. This parable of the poet is based on a simple detail that has been repeatedly mentioned by many authors, including them in their own work - the phenomenon of moths striving for a burning candle. It is said that the moths gather one night and become obsessed with a candle; having agreed, they try to understand the essence of the candle. Then one of them approaches the candle, sees its bright light, and returns to tell the others. But the moths do not understand anything he says, because he cannot explain what a candle is. In the same way, several more moths circle around the candle and tell what they have seen. But "they could not find the spot of the difficult sky," and the goal is not achieved.

*Sham' davrida qanot ko'p urdilar,  
Har biri o'z bol-parin kuydurdilar.*

*Har biri kuyganicha ondin topdi kom,  
Sharhi dushvor erdi-yu naqli harom.*

It becomes clear that every moth enjoyed the light of the candle, yet none could describe it, because the flame cannot be fully explained with words—one cannot comprehend the intensity of the fire without being burned. The final moth, however, fearlessly casts itself into the flame, becoming purified and transforming into the flame itself. In perishing within its goal, it attains the true purpose through *fana*.

*Foniyo, lofi fano urmog'ni qo'y,  
Vasl esa koming, fano o'tig'a kuy.*

*Evrulub sham' o'tig'a parvonor,  
O'zni tashla shu'lag'a devonor.*

Navoi drew two conclusions from this: one - it is impossible to understand the Truth until one is immersed in the light of Truth and burns in the heat of its beauty. The second - a person who has reached the Truth (like a burnt moth) cannot explain this secret. This is the very essence of the Haqq ul-yaqin. That is, becoming mortal, the transformation of the subject into an object, the complete disappearance of the material body and merging with the divine world. A person cannot reach the true essence of truth without being burned in the fire of mortality. The poet, at the

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end of the story, using the pseudonym Faniy, expresses the essence of the valley even more deeply and profoundly. This story is given in Fariduddin Attar's work "Mantiq ut-tair" - as evidence for the Valley of Faqr Fano. It describes the story of two moths trying to compare the light of a candle, but their leader considers it flawed. Finally, when one moth joins the candle and burns, turning into a crimson ember, the leader is pleased with its burning, and the others admire it, and as a result, they all throw themselves into the flame of the candle and perish. The author here explains the levels of knowledge: *ilmul yaqin*, *aynul-yaqin*, and *haqqul-yaqin*. And he evaluates *haqqul-yaqin* as the true perish. Attar's conclusion at the end of the story is as follows:

*Etmasang ko 'yingda joningni badar,  
Senga jonondin nechuk etgay xabar?..*

*Bul maqomga kimsa mahram bo 'lmadi,  
Etmadi, chun unda bir dam bo 'lmadi...*

Navoi uses this story in the section "The True Recollection of the Candle of the Assembly of Moths," but he does not talk about his immediate career, but rather considers the candle as a whole and emphasizes the benefits that can be derived from it. That is, the moths that strive toward the candle and burn together with it attain twofold benefit, as Navoi explains:"

*Bir bukim, kuymay anga etmas kushod,  
Bo 'lmag'uncha kul topo olmas murod.*

The word "ash" in the verse is used through the art of allegory in the meanings of "burning to ashes" and "wholeness", expressing two different meanings at the same time. Thus, the goal is not achieved until the body is completely consumed in the fire of *fana*. The lover does not comprehend *kull*—the sense of entirety or wholeness—until he has burned and turned to ashes."

*Yona bir bukim, etib bu nav' barq,  
Onikim o't bahri ichra qildi g'arq.*

Only the one who has burned truly becomes aware of the essence of the candle, and at the same time forgets both oneself and others, perceiving nothing but the flame itself.

Navoi also refers to the symbols of the candle and the moth in the section of the epic '*Lison ut-Tayr*' titled 'When the king of birds was perplexed for not finding the answer, the Hoopoe informed him about the Simurgh.

*Hudhud ul nuri xiraddin bahramand,  
Rohbarlig' afsaridin sarbaland...*

*Kirdi ul majma' aro devonavor,  
Sham'i maqsud vasfida parvonavor.*

That is, Hudhud enjoys the light of the mind (closeness to Simurgh), his head is held high with the crown of leadership, says the poet, and he sees the reason for this in being a butterfly to the candle of the goal. In this, being a butterfly to the candle means being close to it, or more precisely, being a confidant to it. The goal is also perfect - because Hudhud, according to Navoi's definition, is a perfect person and a perfect teacher who has made his soul perfect for the Beloved.

## Conclusion

Therefore, in Navoi's work, and especially in the epic poem "Lison ut-tair", the candle symbolizes absolute beauty and perfection, while the moth represents the spiritual seeker who has reached perfection in the love of this beauty and perfection, reached the stage of *fana*, but has not revealed their love, embodying the figure of the arif salik on the path of *sahb*.

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## HOUSEHOLD TIMBER PRODUCTION, AFFORESTATION, AND FOREST COVER CHANGE IN ZAMBIA: PANEL EVIDENCE FROM NORTH-WESTERN AND EASTERN PROVINCES

**Abstract:** Zambia has forests that cover about 60 percent of the entire land in the country but the role of afforestation as a moderating process is empirically under-explored at the district level. The paper considers the role of household involvement in timber production in the change in forest cover among 30 districts in North-Western and Eastern Zambia between the year 2019 and 2024 based on a balance panel of 180 observations and a two-way fixed-effects (FE) regression model. An interaction term is included to determine whether conservation programs are able to mitigate the adverse ecological impact of extraction through a moderating variable - afforestation intensity. Findings indicate that household timber participation has statistically significant negative impact on forest cover ( $= -0.041$ ,  $p = 0.01$ ), which is resistant to proxy substitution (charcoal production,  $= -0.052$ ,  $p = 0.05$ ) and one year lagged specification ( $= -0.044$ ,  $p = 0.1$ ). Importantly, the timber  $\times$  afforestation interaction coefficient is (critically) positive and significant ( $0.001$ ,  $p < 0.01$ ), which confirms the buffering effect: the decreases in forest cover to one unit of timber activity are significantly less in the districts characterized by the high intensity of afforestation. The model accounts about 95 percent change in forest cover ( $R^2 = 0.947$ ). These results allow concluding that active afforestation policy can separate household economic extraction with extensive ecological degradation, assuming that the rates of planting and extraction increase in the same proportion.

**Key words:** forest cover change; timber harvesting; afforestation; fixed-effects panel model; Zambia; forest conservation; rural livelihoods.

**Language:** English

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### 1. Introduction

Forests in Sub-Saharan Africa are some of the most ecologically and economically important forests in the world with sequestration of carbon, conservation of biodiversity, soil and water management as well as direct livelihood source to hundreds of millions of rural households. Zambia is a case of special interest: forests occupy approximately 60 percent of the country land mass and support rural livelihoods on large areas of miombo woodlands. However, there is a continuous and increasingly rapid degradation of these forests, which is a result of a compound of agricultural encroachment, charcoal

burning, and commercial and subsistence timber harvesting. The country has experienced some of the worst forest cover loss rates in the Southern African Development Community (SADC) region between 2000 and 2024, with government estimates indicating that the country is losing more than 250,000 to 300,000 hectares of woodland annually.

The central issue to this dilemma is a socioeconomic conflict. To the rural population in North-Western and Eastern Provinces - the two most productive timber areas in Zambia - forest products are not luxurious items but essential survival resources. Timber income forms an important or

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auxiliary source of income to the households, and charcoal production offers an easily available livelihood back-up in situations where alternative agricultural alternative activities are not viable. This economic dependence renders solely restrictive conservation policies both politically and practically hard to support.

Although it is evident that there has been an increased literature on African deforestation, dynamics unique to the high-production timber districts in Zambia are not fully comprehended. The available research is usually at the national level, uses cross-sectional designs, which are not able to consider the heterogeneity of the district, or uses conservation initiatives as exogenous but not as moderating the activity. More importantly, no research has utilized a panel econometric model to analyze household involvement in timber and afforestation intensity as interacting variables of forest cover change in primary timber-producing areas in Zambia.

The paper fills these gaps by relying on a purpose-designed panel survey of 30 districts in North-Western and Eastern Zambia followed up over six years (2019-2024). The research aims at achieving three objectives that are interrelated, which are first, to measure the direct impact of household involvement in timber production on forest cover change; second, to determine whether afforestation programs mediate this interaction; and third, to determine the policy implications of the need to balance livelihood support with the protection of forests. The two-way fixed-effects model used here balances the fixed-in-time variables of characteristics of the district and annual shocks on the macro economy, which can cause more believable causal inference compared to the previous descriptive methods.

The rest of the paper goes as follows. Section 2 is also an overview of the theoretical and empirical research on timber production, household extraction behavior, and forest conservation policy. Section 3 includes the study region, data, and econometric plan. The empirical results are described and discussed in Section 4. Section 5 concludes the policy and provides further research directions.

## 2. Literature Review

### 2.1 Forests as Common-Pool Resources and the Extraction Biomass Nexus

The connection between timber harvesting in the household and forest biomass is best fruitfully interpreted in the frames of common-pool resource theory. When forests are treated as open-access or poorly managed commons, the cumulative ecological cost of each individual extraction decision on other users and future generations is not internalized. Models of resource economics predict that in the unregulated extraction scenario, there will be a tendency to rise above regeneration limits resulting in

a more rapid depletion. This is supplemented by ecological models that focus on carrying capacity: extracting at levels that exceed some threshold changes the stand composition, decreases species diversity and impacts the ecosystems ability to provide services.

The tendency of the predictions is widely supported by empirical evidence. The Ethiopian, Tanzanian and Democratic Republic of Congo household surveys show that the distance to large forest patches strongly predicts per-capita volume of extraction, whereas households in exhausted regions substitute or diversify livelihoods suggesting a strong feedback between biomass availability and harvest behavior. This response is non-linear: when remote, high biomass areas can receive a lower harvest intensity, but integration into the market and the enhancement of road infrastructure can take even high-biomass stands to the extraction frontier.

Extraction intensity is further mediated by socioeconomic factors including household size, income diversification, land tenure security and market access. In environments of low enforcement and high timber prices, households that have de facto access to unprotected forest patches have a much higher rate of extraction. Economic crises and price spikes cause boom extraction waves that surpass the sustainable yield levels. Such processes become especially relevant in the miombo woodlands of Zambia where economic options are scarce and timber and charcoal markets are part and parcel of rural livelihood portfolios.

### 2.2 Plantation and Afforestation Policy: The Conservation Benefit Hypothesis

One of the leading streams of forest policy writing develops the plantation conservation benefit hypothesis: that managed tree planting, whether in government-funded programs, commercial forestry, or community-based initiatives, will take the pressure off natural forests as wood will be available in other uses, in managed trees. This is theoretically consistent with the land-sparing framework: with the production of timber concentrated and highly productive in specific areas, the marginal profitability of extracting natural forest stands should go down.

Empirical evidence of this mechanism is however mixed and context-dependent. Cross country research indicates that the growth of plantations is commonly linked to a falling rate of deforestation, yet determining causation is also complicated by reverse causality - plantations tend to be set up in those regions where the natural process of deforestation has already reached an advanced stage - and by the forest transition theory, which postulates that countries move through a predictable pattern of net deforestation to net forest gain as they develop, regardless of plantation investment itself. Econometric modelling also points to a rebound risk: in which

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timber demand is price elastic, the negative costs of a plantation sourced supply can actually trigger an overall consumption that undermines conservation benefits.

The moderating effect of afforestation programs at local and household level is even less understood. Not many studies have carried experiment on whether community level or district level planting intensity alters the forest-cover implications of household timber extraction by panel econometric techniques. This is the main omission in the analysis that the current work deals with.

### 2.3 Forest Governance and Policy in Zambia

The forest governance system in Zambia includes Forests Act (2015), the National Forest Policy (2014), and other international obligations within the frames of REDD+ and the Paris Agreement. The legal framework draws boundaries of national forests, local forests, and private forests and stipulates sustainable forest management plans. Practically, the level of enforcement is limited by a lack of budgetary means, the low density of inspectors, and the political nature of the restriction of timber-based livelihoods.

CBFM has been promoted as an adjunctive governance system, intended to decentralize management to the local community and harmonize the incentives of households with conservation goals. There is some evidence of this in CBFM programs in Zambia and neighboring countries which indicate that in situations where communities are granted meaningful tenure rights and tangible benefits as a result of conservation, forest degradation can be mitigated. Nevertheless, the magnitude of CBFM is still less in comparison to the scope of uncontrolled extraction, and the correlation between formal reforestation programs and household extraction behavior is not quantified strictly.

Such gaps in knowledge are practically consequential: in the absence of evidence about how afforestation can affect the effects of timber extraction at the district scale, the magnitude of replanting needed to counter the effects of harvesting-related degradation under varying policy assumptions cannot be measured. This paper gives that evidence.

## 3. Methodology

### 3.1 Study Area

The sample size of the study includes 30 districts, spread over North-Western Province and

Eastern Province of Zambia, which were chosen as they control the national timber production and the administrative records of the districts are consistently available. The North-Western Province is a huge miombo woodland and contains the highest concentration of commercial timber licensing in the country. Eastern Province is typified by subsistence and small-scale commercial timber harvesting as well as large-scale charcoal production into urban markets. The two provinces alone contribute most of the recorded timber volume in Zambia and represent different institutional and ecological settings, which offer analytical diversity that is vital in establishing moderation of afforestation.

### 3.2 Data and Variables

The sample is a balanced sample of 180 district-year observations (30 districts, 6 years, 2019-2024). Data were gathered using primary methods, i.e., structured survey tools at the district level in co-operation with Zambia Forestry Department. Remote sensing products that were cross-validated with national forest inventory records were used to obtain secondary data on forest cover change. All monetary variables are in constant US dollars.

Table 1 indicates descriptive statistics of all variables. The mean of the dependent variable- forest cover change (cover) is -3.259 percentage points/ year (SD = 1.273), which proves a systematic trend of net forest loss within the study area with each district showing a decrease of between -0.8 to -7.2 percentage points per year. The main explanatory variable, household timber production participation (timber) has a mean of 25.39% (SD = 13.37) meaning that timber is an activity that is widely practiced in the livelihoods. Charcoal production participation (charcoal) is equally high at 24.23 (SD = 8.31), which gives a closely related proxy of robustness. The mean household average monthly income earned by timber activities is USD 335 (minimum: USD 11.40, maximum: USD 2,516), which indicates a high intra-district inequality. The distance to nearest market is 93.1 km on average meaning that the majority of extraction is in rather remote locations. The afforestation variable is measured through the intensity of reforestation initiatives on a district level (units: planting interventions per year), the average of which is 23.1 units.

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**Table 1: Descriptive Statistics of Study Variables (N = 180)**

Variable	Description	N	Mean	SD	Min	Max
cover	Annual change in forest cover (%)	180	-3.259	1.273	-7.200	-0.800
timber	Household timber production participation (%)	180	25.39	13.37	0.500	47.60
charcoal	Household charcoal production participation (%)	180	24.23	8.31	7.400	45.90
income	Average household monthly income from timber (USD)	180	335.2	636.2	11.40	2,516
priceflact	Timber price fluctuation (%)	180	7.994	38.45	-63.30	143.1
area	Total area under timber production (ha)	180	16,760	31,812	570	125,800
tax	Annual tax revenue from timber activities (USD)	180	17,232	32,707	590	129,330
distance	Average distance to nearest market (km)	180	93.10	40.46	34.90	177.5
gdp	GDP from forestry and logging (USD million/yr)	180	137.9	326.5	0.570	1,258
extraction	Mean timber extraction intensity (m <sup>3</sup> /yr)	180	4.177	2.695	0.320	11.27
reforest	Afforestation initiative intensity (units/yr)	180	23.10	-	-	-

Source: Survey data from North-Western and Eastern Zambia (2019–2024). Forest cover change derived from remote sensing cross-validated with national forest inventory records.

### 3.3 Econometric Strategy

The study employs a two-way fixed-effects (FE) panel regression to identify the relationship between household timber participation and forest cover change. The baseline specification takes the form:

$$Y_{it} = \alpha_0 + \alpha_1 X_{it} + \alpha_2 Z_{it} + \lambda_i + \mu_{it} + \varepsilon_{it} \quad (1)$$

where  $Y_{it}$  is forest cover change in district  $i$  at time  $t$ ;  $X_{it}$  is household timber production participation;  $Z_{it}$  is a vector of control variables (income, price fluctuations, area under production, tax revenue, market distance, GDP, and extraction intensity);  $\lambda_i$  captures unobserved time-invariant district characteristics (geography, institutional history, soil quality);  $\mu_{it}$  controls for common macro-economic shocks in each year; and  $\varepsilon_{it}$  is the idiosyncratic error

term. Standard errors are clustered at the district level to account for within-district serial correlation.

To examine the moderating role of afforestation, the analysis extends to a moderation model:

$$Y_{it} = \gamma_0 + \gamma_1 X_{it} + \gamma_2 M_{it} + \gamma_3 (X_{it} \times M_{it}) + \gamma_4 Z_{it} + \lambda_i + \mu_{it} + \varepsilon_{it} \quad (2)$$

where  $M_{it}$  is afforestation/reforestation intensity, and  $X_{it} \times M_{it}$  is the interaction term. A statistically significant positive  $\gamma_3$  would confirm a buffering effect: higher afforestation attenuates the negative impact of timber extraction on forest cover. The Hausman test confirmed the appropriateness of FE over random effects ( $p < 0.01$ ). All estimations are conducted in Stata using the `xtreg, fe` two-way specification.

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Three robustness checks are implemented. First, the core explanatory variable is substituted with household charcoal production participation, which is a closely related but distinct proxy for forest extraction pressure. Second, a one-year lagged specification of timber participation is estimated to address potential simultaneity bias — specifically, the concern that forest cover change itself may influence household extraction intensity. Third, model fit and coefficient stability are assessed across the baseline and moderation specifications.

#### 4. Results

##### 4.1 Descriptive Patterns: Decreased Systematic Forest Covers

When the 30 districts track the forest cover longitudinally over 2019-2024, a net decreasing pattern is observed across most of the 30 districts. The average loss is 3.26 percentage points per year with the intermediate cross-district standard deviation of 1.27, which means that degradation of forests in this sample is not caused by a few outliers but represents a general phenomenon in the region. The paths of individual districts are quite parallel in general, which indicates that the driving forces, which are mostly the household extraction, are relatively stable and evenly spread throughout the study area.

The comparison of extraction and afforestation trends shows that the structural imbalance has continued to be the same the extraction intensity every year has always been higher than the output of afforestation over the study period. Although there is a positive but slight increase in reforestation activities during the later years of the panel (2022-2024), the net

change in forest stocks between harvesting and replanting reveals that the net stocks of forests are decreasing. This extraction-afforestation asymmetry gives the empirical rationale behind the use of afforestation as a moderating variable: despite the fact that the modern rate of planting is too low to achieve a net-neutral effect, the fact that planting intensity varies across districts and across years offers a plausible source of moderating impact.

The comparison distribution of timber and charcoal involvement indicates that the two activities are widely spread with charcoal making being more varied with a higher median participation rate in a number of the districts. Localized outliers are an indication of spatial clustering of extraction activity around urban timber and charcoal markets, which is in line with the importance of market proximity in determining the intensity of extraction.

##### 4.2 Timber Regression: Direct Timber Impact.

The outcome of the baseline two-way fixed-effects regression is indicated in Table 2. The household timber participation coefficient is -0.041 which is significant at 1% level ( $p < 0.01$ ). It means that the one-percentage-point change in the proportion of households engaged in timber production correlates with a decrease in the forest cover in the district by 0.041 percentage points per year, other factors held constant, the district fixed effects, the year fixed effects, and all the control variables. With a mean timber participation rate standing at 25.39, this will suggest that there is a high aggregate pressure on forest cover.

**Table 2: Baseline and Moderation Fixed-Effects Regression Results**

Variable	Model 1: Direct Effect	Model 2: Moderation Model
timber ( $\beta_1$ )	-0.041*** (0.014)	-0.059*** (0.015)
reforest ( $\beta_2$ )	-0.034* (0.019)	-0.074*** (0.023)
timber $\times$ reforest ( $\gamma_3$ )	—	0.001*** (sig.)
income	0.049 (0.071)	0.036 (0.069)
priceflact	0.000 (0.001)	0.000 (0.001)
area	0.002 (0.006)	n.s.
tax	-0.003 (0.006)	n.s.
distance	0.312 (0.233)	n.s.
gdp	0.000 (0.002)	n.s.
extraction	0.041 (0.049)	n.s.
District FE	Yes	Yes
Year FE	Yes	Yes
N	180	180

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R <sup>2</sup>	0.947	0.947
Adjusted R <sup>2</sup>	0.930	0.930

Standard errors in parentheses. \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ . n.s. = not significant. Source: Author's estimation from survey panel data.

All economic control variables, including but not limited to household income, changes in price, area under production in total, tax revenue, market distance, and district GDP are all statistically insignificant at traditional levels in the basic model. The result is informative in theory: the breadth of household involvement in timber extraction (the participation margin) is a better predictor of forest cover change, than the intensity or financial payoff of the extraction itself, when other predictors of the change (district and year fixed effects) are controlled. The explanatory power of the model is large ( $R^2 = 0.947$ ), which means that the given variables along with the fixed effects structure account nearly 95 percent of the variance in annual forest cover change.

#### 4.3 Robustness Checks

The baseline finding is confirmed by two robustness checks. To begin with, substituting household timber participation with household charcoal production participation provides a coefficient of -0.052 ( $p < 0.05$ ), which confirms that the negative relationship between forest extraction activities and forest cover is not exclusive to the timber sector but is a more generalized pattern of household-level forest pressure. The somewhat greater coefficient of charcoal (compared to timber), is in line with the more diffuse spatial distribution of charcoal production and the fact that charcoal production depends on the burning of a more woody biomass over a greater area of land per unit of production.

Second, timber participation (L.timber) has a one-year lagged specification, the coefficient (-0.044) of which is less than  $p = 0.10$ , which supports temporal precedence. The implication of this finding on causal interpretation is that the adverse impact of timber extraction on forest cover extends over time, and the lagged specification is intended to deal with the potential that forest degradation was also influencing household extraction decisions and not the other way around. The adjusted  $R^2$  of the lagged model (on a reduced data set of  $N = 150$ ) is high and again proves the stability of the model.

#### 4.4 Moderation Analysis: Buffering Role of Afforestation

Table 2, Model 2 shows the moderation specification. When afforestation is introduced as a moderating factor and a timber x afforestation interaction term is added, the picture is altered considerably. The direct coefficient on timber

participation increases in absolute value to -0.059 ( $p < 0.01$ ), indicating that the estimate at the base was, to some degree, softened by the positive moderating impact of afforestation. The afforestation coefficient (reforest) is also negative and significant (-0.074,  $p < 0.01$ ) which can be explained by the fact that the reforestation activities are disproportionately concentrated in the districts with the most acute degradation a sort of policy targeting that generates a negative unconditional correlation between reforestation and forest cover.

The interaction term coefficient is the critical item: it is positive and highly significant ( $\gamma_3 = 0.001$ ,  $p < 0.01$ ). This is a confirmation of the hypothesized buffering effect: with each unit of afforestation intensity, the adverse marginal impact of timber participation on forest cover is neutralized partially. Marginal effects analysis - using a conditional effects plot to show the slope of the timber-cover relationship at low, average and high levels of afforestation intensity reveals that the rate of depletion is steepest in low-afforestation districts and is significantly flattened in high-afforestation districts. The tangling of these slopes at elevated levels of afforestation give strong graphical proof that proactive conservation policy can separate the rate of extraction and the rate of ecological decline, without necessarily reducing timber activity directly.

Notably, the overall  $R^2$  in Model 2 is equal to 0.947, showing that the introduction of the interaction term does not enhance explanatory power through overfitting, but instead it reallocates the explanation of variance between the two main effects and the interaction. The presence of socioeconomic controls is similarly not significant in either of the two models, which supports the idea that the rate of participation and forest conservation response is the most important determinant of forest cover in this regard, and not income levels or market conditions.

## 5. Discussion

### 5.1 Theoretical Contributions

This research paper is relevant to a number of theories in forest and environmental economics. Regarding Common Pool Resource theory, the findings affirm that extraction of common-pool uncontrollable households generates statistically significant and economically important depletion of the forest. More importantly, the paper builds upon this framework and shows that the relationship between extraction and ecological performance can be changed through institutional responses, i.e.

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afforestation programs, without assuming that CPR degradation is an unavoidable consequence of household economic behavior in the absence of privatization.

The results also have implications on the body of literature on the Environmental Kuznets Curve (EKC), which assumes that the relationship between income and environmental degradation is inverted-U. It is worth noting that income of households can be statistically insignificant in both model specifications, which indicates that growth in incomes is not sufficient to stimulate forest recovery in this scenario. Rather, the environmental improvement mechanism is the targeted institutional interventions, which are afforestation programs, and are independent of income trajectories. This difference is practically significant: it means that conservation of forests does not have to wait until EKC turning points are reached by income but can be promoted by conservation policy itself.

In relation to the plantation conservation benefit hypothesis, the research gives panel-level evidence at the district level that afforestation indeed moderates extraction-induced forest loss as hypothesized. Nevertheless, the continuing negative unconditional coefficient on afforestation validates the fact that the present rates of planting are not enough to counter the extraction - the afforestation gap observed in descriptive analysis. This agrees with the literature finding that the conservation value of afforestation is context dependent and is most plausible when the planting area is proportional to the area of harvesting.

### 5.2 Implication on Forest Management in Zambia

The empirical findings have direct implications on the forest management in the North-Western and the Eastern Provinces of Zambia. The result that the breadth of timber participation (as opposed to extraction intensity per household) is the strongest predictor of forest cover change implies that the policy that is based on individual household quotas can be less effective as compared to the one that targets the overall rate of participation. Diversification programs of livelihoods based broadly to ensure that timber is no longer the main income generation source should therefore be prioritized.

The effect of afforestation moderation demonstrated is practically encouraging: it indicates that conservation investment is indeed translated into quantifiable protection of forest cover, despite the continued extraction pressure. Nonetheless, the afforestation gap that has continued to exist throughout the six years of analysis i.e. extraction always exceeds replanting suggests that the scale of current programs cannot be applied to achieve net-neutral or net-positive forest cover. To achieve extraction rates by afforestation, program budgets,

community engagement capacity and monitoring systems would need to be significantly increased.

The strength of charcoal outcome (coefficient is even more negative than timber) deserves certain policy consideration. The diffuse spatial distribution and the high rate of biomass-per-unit-of-output consumed in charcoal make it especially harmful as a form of extraction. More efficient carbonization and formalization of the charcoal value chain may help lower the unit biomass price of charcoal production by a significant margin without abolishing the livelihood activity.

### 6. Policy Recommendations

According to the empirical evidence, four policy recommendations are put forward to the forestry authorities, provincial governments and development partners in Zambia:

**Decentralized, extraction-linked afforestation.** The moderating influence of afforestation as shown is most significant at high levels of planting, yet the current program arrangement fails to progressively connect extraction authorization and replanting responsibility. There must be policy that household or cooperative timber licenses must be accompanied with corresponding local afforestation commitments. Such a connection would make the buffering effect found in the moderation model operational and dynamically scale reforestation to extraction pressure.

Diversification of livelihoods in order to lessen rates of participation. Because the main cause of forest cover loss is the level of timber involvement, one of the high-priority leverages is the overall **household reliance on extractive forest activities**. Timber and charcoal extraction: the Ministry of Agriculture and Livestock, through NGOs and development banks, should provide more access to non-extractive forest-based livelihoods apiculture, sustainable fruit and nut harvesting, ecotourism and climate-sensitive agricultural options that make timber and charcoal extraction unnecessary.

**Charcoal value chain formalization.** Seeing that the production of charcoal has a more adverse per-unit effect on forest cover than commercial timber, this sector should be formalized. In particular, the cost of biomass per ton would decrease due to the effective use of kiln technology, geographic rotation of extraction areas, and mobile monitoring units, and allow identifying the extraction hotspots in real-time. Spatial planning of extraction and afforestation would be planned with formal charcoal production zones, which are similar to controlled timber concessions.

**Proactive management using early-warning systems.** The importance of the year fixed effects in both models specifications makes it clear that annual macroeconomic shocks, price fluctuations, economic downturns, climate stress events, and so on, have an effect on the extraction intensity. Forestry authorities

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need to come up with early-warning mechanisms that track timber price indices and GDP trends in real-time so that Payments to Ecosystem Services (PES) or conservation subsidies can be scaled-up preemptively when the extraction pressure is high. Countercyclical conservation finance would eliminate waves of survival-induced deforestation during the lean economic times.

### 7. Conclusion

This paper presents stringent panel econometric analysis on the interaction between household timber production, afforestation policy, and change in forest cover in the top timber producing districts in Zambia. Three major findings are found. First, the participation of household timber production has statistically significant and practically relevant negative impact on forest cover ( $\beta = -0.041$ ,  $p = 0.01$ ), which is resistant to proxy substitution, lagged specification, and model re-specification. Second, afforestation programs have a strong positive moderating impact: the faster the district is planted, the smaller the decline in forest cover per unit of timber activity, which supports the hypothesis of buffering. Third, even with the proven protective role of afforestation, the structural extraction-replanting gap is still present throughout the study period which implies that the current conservation is not enough to achieve net-neutral forest results.

Theoretically, the findings contribute to the Common Pool Resource frameworks by showing that institutional responses may modify extraction degradation dynamics, are not consistent with income-driven Environmental Kuznets Curve accounts since conservation investment, and not income growth, can cause forest improvement, and confirm the plantation conservation benefit hypothesis at the district scale and underscore the importance of adequate program scale.

In practice, the results can be used to argue in favor of extraction-linked afforestation requirements, widespread diversification of rural livelihoods, formalization of the charcoal value chain, and responsive forest governance to economic shocks. The analytical model created here, a two-way fixed-effects moderation model, using district-level panel data, can be generalized to other high-extraction woodland settings in Southern and Central Africa, which offers a model of evidence-based forest policy in the area.

In the future, studies need to examine long-term survival of reforestation programs found in this study, spatial no homogeneity of the afforestation buffering effect at sub-district levels, and whether digital monitoring technologies can be used to implement real-time adaptive management of extraction-afforestation balances.

Supervised by: Prof. Song Yanping 宋燕平

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## IMPROVING THE ACCESSIBILITY OF TRANSPORT SERVICES FOR THE POPULATION, ON THE EXAMPLE OF THE REPUBLIC OF KARAKALPAKSTAN

**Abstract:** The article examines issues of improving the accessibility of transport services for the population using the example of the Republic of Karakalpakstan. Transport plays an important role in the socio-economic development of the Republic of Uzbekistan, ensuring conditions for economic growth and increasing the competitiveness of the national economy through the quality of services provided.

**Key words:** road transport, transportation, economy, export, transport services, public transport.

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### Introduction

Transport plays an important role in the socio-economic development of the Republic of Uzbekistan, ensuring conditions for economic growth and increasing the competitiveness of the national economy through the quality of services provided. The technological, value, and geographical availability of transport services determines the territorial development of economic relations and the possibility of meeting the needs of the social sphere both within the country and abroad.

In the context of modern rhythms of life in large cities, the most important type of transport is urban passenger public transport. A feature of the territorial structure of the city of Nukus is the high level of mutual integration with the Republic of Karakalpakstan as a whole, and especially with the Republic of Kazakhstan. According to Karakalpakstat, the total length of roads in the Republic of Karakalpakstan is 42,869 km, of which

50-100 km of roads (A-380 highway) pass through the city of Nukus, while about 4.8-6.6 thousand cars enter the city daily from the main routes, which belong to residents of nearby districts and villages operating in the city.

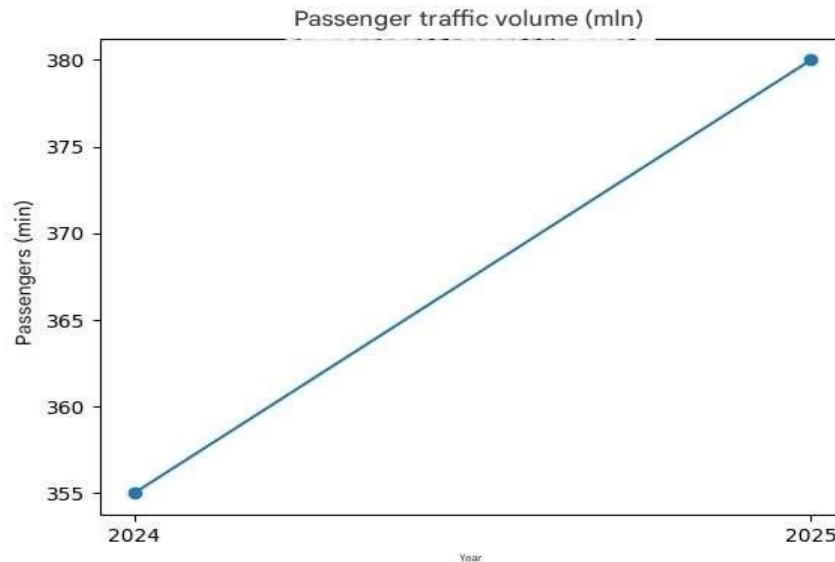
Thus, the greatest accumulation of vehicles is observed on the main highways of the city of Nukus, where the load factor of all highways is 1.0-2.0 times higher than the limiting normative coefficient, which ensures unimpeded and uninterrupted movement of vehicles along highways.

According to Karakalpakstat, as of December 31, 2025, there are about 160,000 passenger cars in Karakalpakstan, which is second only to Tashkent, Tashkent region, Samarkand, Bukhara, and other cities in Uzbekistan. According to the statistical data presented in the table and Fig. 1, 1a, 350-400 thousand people were transported in the city of Nukus in 2025, which is 4-5% more than in 2024.

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**Table 1. Main Indicators of Passenger Transportation in Nukus City for 2024–2025**

Indicator	2024	2025
Number of passengers	340–370 mln	360–400 mln
Growth rate	~104–105%	~105–106%
Primary mode of transport	Vehicle	Vehicle
Share of the private sector	Very high (~90%+)	Preserved



**Figure 1. Dynamics of Public Transport Passenger Volume in 2021–2025**



**Figure 2. Comparative Trend of Public Transport Use in Nukus City**

Figure 1 - Number of passengers transported by public transport, thousand people. As can be seen from the analysis, a steady decline in the use of public transport can be observed in 2021-2025. This decline may be due to a number of reasons, such as:

- constant growth in the number of cars owned by citizens;
- transition to personal accounting of unified social travel tickets.

The rapid growth of the number of cars in the city of Nukus and districts, the accelerated growth of their motorization, and the insufficient development of the road network and transport infrastructure in general led to the need to expand access to transport services for the population. To achieve this goal, the

"Transport Strategy of Uzbekistan until 2030" was developed and adopted at the state level, the main tasks of which related to increasing the accessibility of transport services for the population are::

- planning the development of passenger transportation systems and rolling stock based on the forecast of the country's socio-economic development and its transport and economic balance;
- creation of transport programs and mechanisms for their implementation;
- development of passenger transportation on socially significant routes;
- development of a competitive market model for affordable and high-quality transport services;

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- implementation of modern information technology-based ITS in urban, suburban, and local transport systems;
- improvement of permits for commercial persons to carry out passenger transportation;
- development of multimodal passenger transportation schemes on regional, interregional, and international routes, etc.

Thus, to solve the main tasks outlined in the transport strategy of Uzbekistan until 2030, it is necessary to develop a program "Development of the transport system within the structural boundaries of the city of Nukus and its territories," which provides for the following areas of transport policy:

- in the sphere of increasing the competitiveness, convenience and quality of passenger transportation:
- increasing the mobility of the population through the priority integrated development of all public transport systems;
- expansion of the effective radius of urban and intercity socio-economic activity through the development of high-speed transport;
- creation of a competitive, affordable, and high-quality passenger transportation market;
- provision of socially significant passenger transportation.

Planning to ensure increased mobility of the population of the city of Nukus through the priority integrated development of all public transport systems. This concerns the development of public transport infrastructure and systems on urban and intercity routes, as well as on transport routes connecting the main centers of socio-economic development.

Along with the development of public transport, it is necessary to implement measures aimed at increasing its attractiveness to private cars, including by regulating the conditions for entering, moving, and stopping private vehicles on the busiest streets of the road infrastructure of the city of Nukus, where the transport problem is especially acute. Implementation of a project to create a paid parking lot in the territory of the city of Nukus in order to create conditions for the convenient movement of pedestrians, public transport, and cars, the main tasks of which are:

- reduction of traffic violations on the road network;
- increasing the speed of movement in paid parking lots;
- increasing the turnover of parking spaces;
- reducing the flow of personal vehicles entering the paid zone and encouraging the use of alternative modes of transport.

Within the framework of this project, designed for 2030, electric buses were introduced to the public transport system of the city of Nukus for the first time at the beginning of 2026.

These electric buses were imported from China and will serve public routes. The first batch of 12 electric buses is planned to be launched on city routes. The goal is to provide modern, clean, and environmentally friendly vehicles for urban transport in the Nukus region.

A project for the development of electric buses and their service infrastructure for Nukus is being developed in cooperation with the European Bank for Reconstruction and Development. Through this project:

- Acquisition of electric buses,
- Charging infrastructure,
- It is planned to create conditions for the maintenance of the park.

The project cost is estimated at approximately 55 million US dollars.

Thanks to this investment, the **e-mobility** (electronic transport) capabilities of urban public transport will be expanded and harmful emissions into the atmosphere will be reduced.

At recent official meetings, the European Bank for Reconstruction and Development proposed expanding strategic support for the introduction of electric buses in the cities of Nukus and Samarkand.

This means that electric buses are not only a means of transport, but also an important step towards the green transformation of urban transport. It is directed towards the adoption of state support measures. All this will create conditions for increasing the efficiency of the transport services market, as well as increasing the accessibility of transport services to the population.

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## ANALYSIS OF INTERNATIONAL TRANSPORT AND LOGISTICS CENTERS FOR THE ESTABLISHMENT AND DEVELOPMENT OF LOGISTICS IN KARAKALPAKSTAN

**Abstract:** The article examines methods for improving the transportation system based on a logistics approach, using the Nukus–Muynak route as a case study. The relevance of this study stems from the need to improve the efficiency of transport services in regions characterized by low population density and significant distances between settlements. The existing problems in the route's operation were analyzed, including uneven passenger flow, the wear and tear of rolling stock, and insufficient coordination of transport processes. Recommendations were proposed for optimizing the route network, implementing digital technologies for monitoring and managing transportation, and rationally allocating transport resources. Particular attention is given to the application of logistical principles—such as a systems approach, integration, and adaptability—which make it possible to improve the quality of transport services and reduce operating costs. The findings can be used to develop regional transport infrastructure programs.

**Key words:** transport system, logistics, passenger transportation, route optimization, regional transport network, Nukus-Moynak, transport infrastructure, transport efficiency, logistical approach, transport digitalization, passenger flow management.

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### Introduction

The Great Silk Road, which emerged in the 3rd–2nd centuries BCE, is considered one of the earliest historical stages in the development of logistical processes. Although the term "logistics" itself was not yet in use during that period, organized flows of goods, resources, and people between cities and states already existed.

The development of trade ties following the military and economic expansions of Ancient Greece and the Roman Empire led to the formation of established transport routes. These routes facilitated not only the exchange of goods but also the transfer of technologies, cultural values, and knowledge.

The operation of the Great Silk Road required coordinating supplies, optimizing routes, ensuring the security of caravans, and storing goods—activities that, in essence, correspond to modern principles of logistics. Thus, one can argue that it was during this period that the foundations were laid for a systematic approach to managing material flows, which became the cornerstone for the future development of logistics as both a scientific and a practical discipline.

Previously (before the second half of the 20th century), logistics was used predominantly in the military sphere and involved organizing the army's supply chain—the delivery of provisions, weaponry,

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and uniforms, as well as managing inventory and troop movements.

In the modern economy, logistics is a comprehensive system for managing flows (material, informational, and financial) aimed at optimizing transportation, warehousing, and distribution processes in order to reduce costs and improve efficiency.

### Methods of Research

International experience in improving transport systems based on logistics principles shows that even in remote territories with low population density, it is possible to create an effective transport model, provided that a comprehensive approach is applied.

For example, Germany's experience demonstrates the high efficiency of logistically integrated transport systems. In Germany, the transport infrastructure operates on the principle of integrating various modes of transport within a single logistics space.

The key element is the concept of integrated transport associations (Verkehrsverbund), which combine bus, rail, and commuter services into a single system. This ensures seamless coordination among all parties involved in the transportation process.

The key features of this model include:

- The implementation of a single ticket valid on all modes of transport;
- Coordination and synchronization of schedules;
- The use of digital management and control systems;
- High precision and reliability of transport operations.

The main conclusion of the German model is that the efficiency of a transportation system is achieved not through an extensive increase in the number of vehicles, but through the optimization and coordination of passenger flows based on logistical principles.

The development of logistics in Turkey demonstrates the highly effective use of the country's transit potential, which stems from its strategic geographical location at the crossroads of Eastern and Western transport corridors. The stability and intensity of transit flows are helping to establish logistics as one of the most dynamic sectors of the national economy.

Regional transport and logistics hubs are being actively developed across the country, integrating major cities with peripheral and remote areas. Key areas for improving the transportation system include creating modern logistics centers, developing high-speed bus routes (express service), implementing digital technologies, including electronic ticketing systems, and adaptively managing transport schedules to account for seasonal fluctuations in demand.

The experience of tourist regions, where the transport infrastructure flexibly adapts to changes in passenger traffic, is of particular importance: During peak seasons, flight frequency is increased and additional transportation resources are deployed, while in the off-season, routes are optimized and operational costs are lowered.

This approach is especially relevant for routes with a heavy tourist flow, such as the Nukus–Moynak route. Applying similar logistical principles will enhance the efficiency of transport resource utilization, ensure the route's operational stability, and improve the quality of public transport services.

In the neighboring Republic of Kazakhstan, regional transport systems are being developed with consideration for specific factors, such as significant distances between populated areas and low population density, which largely mirror the conditions in Karakalpakstan. This necessitates the use of effective logistical approaches in organizing transport services.

Key features of Kazakhstan's transport logistics include state support for inter-district and socially significant routes, the active digitalization of bus services, the implementation of GPS monitoring systems to track vehicle movement, and the development of distribution warehouse complexes and transport and logistics centers.

An overview of international experience in applying logistics methods reveals several universal approaches to improving regional transport systems. These include integrating various modes of transport into a unified network, developing logistics and distribution centers, optimizing route networks using digital technologies, and enhancing the efficiency of traffic flow management. Implementing these initiatives helps to reduce transportation costs, increase the public's access to transport services, and ensure the sustainable socioeconomic development of the regions.

The route between the cities of Nukus and Muynak is a key transportation link in the Republic of Karakalpakstan. The geographical distance of the route is 200–210 km. The only connection between the cities is a regional highway, and the travel time is 3.5–4 hours.

The territory's natural and climatic conditions are characterized by a desert and a sharply continental climate.

The route runs through a sparsely populated area, which significantly impacts the provision of transport services.

Demographics for the cities of Nukus and Muynak are approximately 343,500 and 33,000 people, respectively.

The population of intermediate settlements is about 80,000 people.

The total potential transport catchment area includes over 350,000 people.

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However, the actual passenger traffic is significantly lower due to:

- limited economic activity;
- low travel frequency;
- the seasonal nature of tourism.

The current stage of transport system development is characterized by the active digitalization of management processes. Information technology is becoming a key tool for enhancing logistical efficiency.

An Intelligent Transportation System (ITS) is a set of integrated hardware and software solutions that provides for the automated management of traffic flows.

The main components of an ITS include:

- GPS navigation systems;
- automated dispatch centers;
- electronic ticketing systems;
- traffic monitoring sensors.

The implementation of an ITS allows for the following:

- reducing passenger waiting times;
- improving schedule accuracy;
- lowering operating costs;
- enhancing transportation safety.

Mathematical forecasting models are used to optimize the performance of the transportation

system. For example, the passenger flow forecasting model:

$$P = P_{average} \times K_{season}$$

where: P - is the projected passenger traffic;

$P_{average}$  - average turnover;

$K_{season}$  - Seasonal factor.

These calculations allow for the advance adjustment of the number of runs, helping to avoid both vehicle overload and underutilization.

For regional routes, digitalization offers the following advantages:

- reduced management costs;
- increased transparency of the transportation process;
- improved quality of service;
- greater public trust in the transportation system.

The implementation of digital technologies is especially relevant for routes connecting administrative centers with remote cities, as in the case of the route between Nukus and Muynak.

The analysis of passenger traffic on the Nukus-Muynak route has the following structure (calculation model):

**Table 1.**

Passenger type	Share (%)
Local residents	45
Students	15
Tourists	25
Entrepreneurs	10
Other	5

Average daily passenger flow (estimated):

- Low season: 120–150 people/day
- High tourist season: 300–350 people/day

Annual average:

$$P_{avg} = 220 \text{ people/day}$$

The seasonality coefficient has been determined based on fluctuations in passenger traffic:

- Low season:  $K = 0.7$
- Mid-season:  $K = 1.0$
- High season:  $K = 1.5$

Formula for calculation:

$$P = P_{avg} \times K$$

For example, during the high season:

$$P = 220 \times 1.5 = 330 \text{ people/day}$$

The existing transportation system does not adapt to seasonal changes, which leads to:

- overburdened transport in the summer;
- underutilization of buses in the winter.

Current bus service provides 3–4 routes per day

Bus capacity: 45 seats

Average occupancy: 65–85%

Throughput calculation:

$$Q = N \times V$$

where: N – Number of vehicle trips;

V – Passenger capacity of the bus.

With 4 flights:

$$Q = 4 \times 45 = 180 \text{ place}$$

During the high season, demand exceeds supply (330 people per day), which indicates a shortage of transportation capacity.

### Conclusions

The Nukus–Muynak route holds strategic socioeconomic importance for the region. The current transportation system operates without modern logistical tools, and its efficiency is highly dependent on seasonal fluctuations in passenger traffic.

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## THE GENRE AND ARTISTIC CHARACTERISTICS OF THE LYRICS OF THE KARAKALPAK POET B.GENJEMURATOV

**Abstract:** This article reflects the life and work of the Karakalpak poet Bakhtiyar Genjemuratov. Also, the formal peculiarities of the poet's lyrics, free poems and their genre features, features of the ideological and thematic direction in the poet's poetry, genre features of his poetry and artistic features in it, artistic research in the field of form in the poet's poetry and stylistic features of his poetry are comprehensively revealed.

**Key words:** Poet, Bakhtiyar Genjemuratov, lyricism, formal features, free verse, genre features, poetry of the poet, ideological and thematic direction, artistic features, artistic explorations, stylistic features, types of poems.

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### Introduction

Karakalpak poetry plays a special role in enriching aesthetic views in society. Poetry reaches artistic heights and is considered a spiritual need and a property of the soul. A more in-depth study of these issues is one of the pressing issues in contemporary Karakalpak literary studies. In this work, we aim to study the lyrics of the poet B.Genjemuratov, who holds a special place in the current Karakalpak literary process.

### Main part

One of the poets who has made a significant contribution to the development of modern Karakalpak poetry, both in content and in form, is Bakhtiyar Allambergenovich Genzhemuratov. He was born on May 11, 1959, in the Takhtakupyr district of the Republic of Karakalpakstan. After graduating from the village school here, he entered the Faculty of Philology of the Karakalpak State University in 1980. The «Karataw» magazine and the creative community gathered around it played a significant role in B.Genjemuratov's creative development. From his student years, he became acquainted with the works of famous writers and poets of Karakalpak literature - I.Yusupov, T.Matmuratov, Sh. Seitov. At the same

time, being in a literary environment with fellow poets J.Izbasqanov, K.Karimov, H.Ayimbetov, S.Ibragimov, Sh.Ayapov and K.Reymov also influenced the poet's work.

### Free songs by B.Genjemuratov

Today, we see that the work of the poet B.Genjemuratov has developed considerably in terms of genre. B.Genjemuratov's contributions to Karakalpak poetry are numerous. Specifically, it expanded the genre possibilities of contemporary Karakalpak poetry, refined methods of creating artistic imagery and form, and acquired a unique style in word formation. Verlibraries and muashshaks (genre poem) are one of such genre studies in the poet's poetry. At the same time, through the creation of unique images through skillful poetic language and artistic imagery, the uniqueness of the poet's inner form is clearly felt in his works. In the works of B.Genjemuratov, one can see wonderful examples of free verse. Specifically, "Bir ananiñ balalarına", "Sahra!- Tentekliktiñ anası...", "Zámin tawdağı Ázim Súyin aytımları", "Jeti babamniñ ismin ayt, Jayhun!", "Shóllegenmen pütün diydariña", "Zer-zebil jawında adasqım keler", "Isenemen", "Kónil dápterimde soraw belgisi «?»", "Jarılıs", "Sargışh japıraqlardıñ

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samalları”, “Shashların”, “Gúz sağan usamayman” and in other poems, one can see the boldness and deep inner emotion characteristic of B.Genjemuratov, who freely expresses the poet's intended meaning and conveys his thoughts through deep sorrow and reflections.

Hár nazlı qáдемиñe,  
tas jollar tañlanar,  
tañlayın qağıp:  
«Pah, pah, pah!...»  
Anaw biz óksheniñ qadalğan ornı,  
qıdığın keltirer kógis taslardın:  
«Ah, ah...»  
Tas qılıp jaraca bizdi qudayım,  
júrgen jollarına tóseler edim,  
ókshelelerini súyip:  
«Wah...»[1; 134]

The poet's poem is rich in strong emotions and the inner emotional turmoil of the lyrical hero. In every line, in every word, the poet's feelings of longing and love for his beloved are like a flame burning from his heart. In this case, feelings gradually intensify through the gradational method. At first, the girl's graceful steps make the paths bewildered, then the bluish stones stirred. And finally, the lyrical hero, falling as a stone on his beloved's path, desires to kiss her heels. Thus, the poet intensified the poem's impact by conveying such inner spiritual reflection in free lines. The equality of syllable numbers is not maintained in verses characteristic of free verse. The main characteristic of the poet is that he doesn't build his poems at a steady pace, so it's impossible to read them all at once. At the same time, the poet has his own artistic reading style. In this case, the sound wave is alternating between rising and falling, resonating in various ways.

-saz átirap –  
Zal únsiz...  
Sam-saz japraq –  
Tal únsiz...  
qabağınan qar jawar,  
álip qáwmet Daraqlar.

Tislenedi gerbishler,  
jinkózlener sharaplar:  
“Shayır, gálet ettiñ”, - der  
“Shayır, qattı kettiñ”, - der. [1; 94]  
Poet's «Túrkan oyda «Jeti qaraqshı» gá telmirip  
... « [1; 44] The theme of the Motherland and the idea of its glorification are also reflected in the free verse genre.

Túrkan oyda «Jeti qaraqshı» gá telmirip,  
uwayımlayman jurımdı:  
Topan suwdı umıtqan, Nuw payğambardı  
umıtqan,  
endi **topan qum** basatuğınan biyxabar,  
Jurımdı uwayımlayman.

In this, the lyrical hero worries about the flooding of his homeland and worries about its future.

Furthermore, through the following lines, it calls upon the people to live in unity and harmony, and to appreciate the value of their native land. For example:

Altı ağa alalanıp awzındağın aldırğan jurıtmı,  
tórt ini daralanıp, qağanatın jawğa qaldırğan  
jurıtmı!

Qayıq jasap, topan suwdan saqlap edi Nuw  
payğambar,  
topan qumda janiña arasha túser kimiñ bar!?  
Qutadğu bilig» tiñ qádirin bilmey,  
kesapatna gırıptar bolgan jurıtmı.

In conveying this idea, the poet skillfully utilized the possibilities of the free verse genre. Repetitions of words characteristic of free verse, frequent breakage of lines without a single system, the conclusion of a thought not ending in a single line but presented in 2-3 lines, and the inconsistency of syllable numbers are also common. Moreover, every word used is as if breathing life into it, its impact is incredibly powerful, and it deeply pains the reader's heart. For example, the poet who embodies the aforementioned qualities “Jaqsı adamlardıñ júregi...” [1; 21] dedicated to the memory of the poet T. Matmuratov.

Mashınlar qağıssa Tórtkúl kóshede - 11  
Nákas aytar kúlip: “áne, keregi!” - 11  
Biraq, - 2  
jaralanıp - 4  
qalar desedi - 5  
ıńranıp... - 4  
Jaqsı adamlardıñ júregi... - 9

Turmıs - 2  
shadlıq – gámin teńdey ákeler... - 9  
Onda dos-yaran kóp, tez-tez keledi. - 11  
Sawlıq bolmasa da - 6  
qadaq kóterer, - 6  
Jaqsı adamlardıñ júregi... - 9

As we can see, this poem by B.Genjemuratov falls short of a certain standard. The syllable numbers, depending on how the thought is expressed, are sometimes raised and sometimes lower. In free verse, intonation, logical thought, and meditative thought play a crucial role. The success of a poem written in a free verse form depends on the poet's extensive exploration. However, we must emphasize that the psychological characteristics and mood of the artist's thinking play a significant role in creating this poetic form.

One of the characteristic features of B.Genjemuratov's free verse is the use of repetitions. The repetition of certain words, phrases, and lines helps to reveal the meaning of the poem. The poet conveys the lyrical hero's mood through repetitions. Shows the strength of the hero's feelings. In the poem, special attention is paid to certain words and phrases as a result of their repeated use. The words that define the idea of the poem's content are emphasized logically, and the repetitions have a great impact on the reader.



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qarakók aydarha dúnyanı juttı. [1; 128]

Thus, in these four lines, the poet's thoughts are concentrated on those who waste the world, live like kings, and lose their conscience.

Quatrains in the form of rhetorical questions can also be found in the poet's work.

Aq qoy bar, qara qoy bar.

Nege joq appaq túe?!

Haq oy bar, qara oy bar,

Nege joq appaq kúe?!

In literature, the construction of thought on rhetoric is of particular importance. Because rhetoric is not just a question; the answer lies hidden behind it. Works based on rhetoric encourage readers to think and explore. [2; 80]

The five-line verse form is very rare in Karakalpak literature. Five-line poems have the same formal characteristics as mukhammas poems. However, in the muxammas, the content expressed in five lines, that is, in one stanza, continues in the following stanzas of the poem. The quintets, like the quatrains, embody a complete meaning. In contemporary Karakalpak poetry, the "muxammas" (genre of poetry) is widely used, both in terms of theme and form, with some variation in its origin.

In B. Genjemuratov's poetry, we encounter, albeit rarely, the five-line genre. For example,

Sulıw sıypalamay Sózlerdiń,

Pańqıldaq odalardıń

ushırıp jiberdi húrreyin

júreklerin jarıp jiberdi

qanjarday qayırılğan Qosıqlar.

According to the five-line rhyme scheme, a - a - b - c - d is a mixed, irregular rhyme scheme. At the same time, the number of syllables is not constant. That is, the second row consists of 7 syllables, and the remaining rows consist of 9 syllables. The content of the Five embodies the idea that «male works are essential for our poetry».

The six-line poems played a significant role in conveying diverse themes in B. Genjemuratov's work. One of the first poets in Karakalpak literature to create poetry in the six-line form was X. Turimbetov.

B. Genjemuratov's six-line works also support this point. The poet's free expression of thought in his poems is also found in his six-line verses. Furthermore, the external form is also built on free verse. For example, in the poet's poem "Debdiw";

Million jıl kókireginde saqlağan dártin

tawlar jarılıp shıǵarar, janıp shıǵarar.

Bultlar heshkimge aytpağan dártin

gúrkirep shıǵarar, jılap shıǵarar.

Dúnya bunsha sherli bolǵanı nesi?!

Men qáytıp jarılayın, qaytıp janayın?!

To the word "Debdiw" "Inner pain, grief, sorrow", - is defined in the explanatory dictionary of the Karakalpak language. Thus, this six-line stanza conveys the lyrical hero's perspective on the world and society as a whole, his inner pain and suffering. The

poet masterfully conveys the inner world of a person through parallel animations. When mountains split and burn, and clouds thunder, people ask how to express their heart's pain.

In B. Genjemuratov's six poems titled «A Good Deed», the metaphor «A thousand and one good deeds are to sway like a plane tree, becoming a shade» addresses the issue of people doing good to one another.

Aǵa bolǵım kelmeydi aqıydalarǵa .

Atın arqalaǵım kelmes aqıydalardıń

qosshısı bolıp.

Mıń da bir sawapdur shınarday terbelmek

sayaman bolıp

sahrayı júreklerde...

Overall, in the poet's work, one can observe that the six-line poems are ideologically and thematically structured in a free form.

In B. Genjemuratov's poetry, eight-line verses are frequently encountered. One of the genre characteristics of his \*eight\* (sakkizliklar) is their expression in a \*muashshaq\* (genre of poetry) form. Its themes are very broad, dedicated to celebrating love, faith and conscience, nature scenes, longing, and so on.

Hayranman. Kózdiń táǵdiri – kúlmek, jılamaq.

Al, lábler biyopaday tuyıladı maǵan.

Ómirim – aǵıp atırǵan dáryadan ibarat.

Sezimniń shıńlarınan baslanar saǵam.

Bizler ayılmaǵan dártli jurdaymız.

Delbemen bir nárseni, biraq, bilmege:

«Kózde jas qalmaǵansha nege jılaymız?!

Kózden jas aqqansha kúlemiz nege?!»

In this eight-line poem, the lyrical hero reflects on the mysterious mysteries of the world and its unresolved problems.

In the poet's eight-line poem, alongside the artistic presentation of such philosophical reflections on fate, man, and life, octaves reflecting love occupy a dominant place.

Most of the poet's eight-line poems are presented in a poetic form, where the theme of love and devotion takes center stage. For example, in the April 27, 2000 issue of the newspaper "Youth of Karakalpakstan" (Qoraqalpog'iston yoshlari), a series of poems by B. Genjemuratov titled «Nawrız samalları» (Winds of Navruz) was published [3]. Here the author «Shúkir...», «Túsindir óziń», «Juwap ber», «Ótinish», «Soraw», «Titanik qosıǵım jáne bir ayttır», «Nazlı kúlniń qalsın», «Siz maǵan isenbeń...», «Aychı...» dep atalatuǵım toǵız muashshaqın kirgizgen. Solardan, «Shúkir...», «Nazlı kúlniń qalsın» the muashshaqs consist of eight rows, Gulistan, Genjexan names come from. «Juwap ber» The poem, from which the name Guliston originates, is distinguished by its humorous nature. For example:

Gúlábi qawınday shireń tamıp tur,

Úh! Erniń, kózleriń ne dep janıp tur?!

«Lawlap órtenbeske qoymaspan!» dey me,

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Isen, kúlim qaldı... Bul shın-anıqdur.  
Sáteń murthı, murcız hám saqallılar,  
Tolı góy átirapıń, olar naǵıp júr?!  
Arsız saǵal yańlı jalańqaya bir zat,  
Náyleyin, qálbimde qańsılap shawıp júr...

In the poem, inner feelings are intertwined with light laughter and jokes. Professor K.Orazimbetov noted, "Especially his humorous poem 'Guliston' is very easy to read" [2; 44].

In general, we witness artistic exploration in terms of content and form in the poet's eight-line verses.

Ten-line poems are found in various forms in the works of the poet B.Genjemuratov. Some of them are in free form, consisting of two five-line stanzas, the first two stanzas consist of four lines, and the next stanza consists of two lines.

The poet's ten-line poems, along with lines of 11-12 syllables, also appear in a 7-syllable form. Rhyme is in the form of a paired rhyme. Typically, in poetry, the first line of the initial conclusion, that is, the rhyme of the first pair of lines, is repeated in the very last lines. For example,

«Ele kóp otlarǵa túserseń, ulım»,  
tamshılap suw sepken qarlıǵashlardıń  
órtti óshire almay kúer qanadı.  
Taslardı jandıǵan aqıret – jalınnan  
bir shimshim jipektiń hasıl mamıǵın  
suymurıq qus aman alıp shıǵarmış:  
kózińdi jumǵanıń – júrimiń barlıǵı.  
Otta janıp ketken qarlıǵashlardıń  
kúyigi bawırındı kálap qıladı.  
«Ele kóp otlarǵa túserseń, ulım»

Furthermore, in the poet's work, there is a poem written in a poetic form called the poem "Óziń! Sen!" (You! You!) reflects Professor K.Orazimbetov's remarkable place in science, his work on poetic structure, and his contributions to literature.

Qosıqtıń sırların xalıqqa uqtırǵan,  
Uqtırwshı alım jalǵız ózińseń!  
Wádwásıl shayırlardı Atqa qaqtırǵan,  
Arshıl Alpamıssań Sózde – sezin sen!  
Naǵısın keltirip Túsiniń degeniń,  
Is basqan Altındı artqan ózińseń.  
Shayır qosıǵı atlı Sırlı Kemeniń,  
Batır Bocmanısań – obrazlı sezinsem...  
Asqar Poeziyanıń ayazlı gezin sen,  
Yoshlı Saratanǵa aylandırar óziń! Sen!

In general, although dozens are rarely found in the poet's work, one can see achievements in terms of ideological, thematic, and formal aspects.

In the work of the poet B.Genjemuratov has collections "Saratan" (1990), "Oq qadalǵan ay" (1995), "Ukuzdaryo bitiklari" (ózbek tilinde 2006, 2007-jillar), "Saylandı shıǵarmalar" (2012). For example, the poet's collection «Selected Works», published in 2012 in "Maǵan yar bolǵaysañ, párwardıǵarım", "Sen meniń tajım – taqtım", "Ógiz dárya bitiklari", "Bir túsinińke siymaydı dúnya",

"Limonniń, almanıń hám qardıń iysi", "Jalǵızdı jaratpa taslardı jarat!", "Sızıqlarǵa jayǵaspaydı ses", "Setyabr samalları", "Álwidah, perishtem, álwidah", "Qálbimde ayaz bar altın kelbetli", "Júregimde sayraw baslandı", "Aylı túnge qaytaman endi" consisting of twelve groups. The poetic series presented in each section are built on a deep idea interconnected in terms of content and themes, seemingly reflecting the evolutionary growth paths and talent of the poet's work. Furthermore, one of the distinctive features of the poet's lyrical versification is the cycle of acrostics. This will be discussed in the following sections of the work.

Mo'ychaqlar (Acrostychs) are a key characteristic of B. Genjemuratov's work. In the works of B. Genjemuratov, there are many muashshaqs written in the names of girls. For example, «Seregul» [4; 22], «Hurliman» [5; 48], «Gumisoy», «Guliston», «Genjexon», and «Hurlimanxon» [3] are examples of this.

Another significant contribution of B. Genjemuratov to the development of the \*muashshaq\* genre is that he was the first author to create a series of \*muashshaqs\* in contemporary Karakalpak lyric poetry. We know of the existence of a series of ghazals, a series of mukhammases, and a series of sonnets in contemporary Karakalpak lyric poetry, which have developed based on Eastern and Western traditions. However, the creation of a series of \*muashshaqs\* in our current lyric poetry is a form innovation. For example, in the April 27, 2000 issue of the «Qoraqalpog'iston yoshlari» newspaper, a series of poems by B. Genjemuratov titled «Navruz yellari» (Winds of Navruz) was published. Author of this series he introduced nine muashshaqs «Shúkir...», «Túsindir óziń», «Juwap ber», «Ótinish», «Soraw», «Titanik qosıǵın jáne bir aytır», «Nazlı kúlkiń qalsın», «Siz maǵan isenbeń...», «Aychı...». Five of these 9 problems in the group of problems, that is «Qashan kelesiz?», «Qapasız nege?», «Bul muhabbat pa?», «Titanik qosıǵın jáne bir aytır», «Sizden qashpasam bolmas» the \*muashshaq\* are written in the form of a complete sentence, as mentioned above. Furthermore, in these problems, the poet's skillful use of artistic devices to convey inner feelings is evident.

In the poetry of B.Genjemuratov, there are also muashshaqs in the form of sentences expressing a certain completed thought in terms of syntactic structure. For example, his «Aygúl, sen ráhim et Baxtıyarǵa», «Qashan kelesiz?», «Qapasız nege?», «Bul muhabbat pa?», «Titanik qosıǵın jáne bir aytır», «Sizden qashpasam bolmas» the poems are included. All of these are matters of openness. All these problems convey the meaning corresponding to their name.

Analyzing B.Genjemuratov's work from both genre and formal perspectives, we have witnessed the existence of a unique example of sonnets in the poet's oeuvre. The author titled it «It rained again...»

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Ideologically and thematically, love reflects the inner spiritual world of the lyrical hero.

Jáne jawın jawdı... Júregim – báhár,  
qálbimdi sótedi gúldirmaması.  
Tágdirdiń tábiyatqa uqsaslıǵı bar;  
aybıqáddem edi Gúldiń anası.

Shieler gúllede, mıslı appaq qar.  
Búlbil sayrar edi ishıqı namasın.  
Appaq shie baǵda bir muńlı dilbar.  
sınsıp qoyǵan edi dizeme basın...

Dumanlar serpilip, bultlar tarqaydı.  
Negedur sonda da qálbim sızlaydı –  
shieden alınǵan sharap sırlasım...

Biz jáne otırmız shie baǵında,  
ishıqı-muhabbatıń altın taǵında.  
Qadaq sınsın, biraq, iqlas sınbasın.

Thus, the idea that began in the first two stanzas of this sonnet develops, continues in the next third stanza, and finally the main conclusion is given. Initially, the inner spiritual pain of the lyrical hero is revealed, followed by the reason.

In general, sonnets are built on strict form and content, which requires skill from the poet.

At the same time, it is found in elegies and epigrams in the poet's work. His/Her poem "I Have Many Debts" has an elegiac character.

During the genre analysis of the poet's work, we witnessed the presence of poems titled "Horse Elegy", "Conscience Elegy", and "Elegy" in the collection «Saratán»

An elegy is a sorrowful song. A type of lyric poetry that deeply reflects the inner feelings of a hero. In elegiac works, the depiction of deeply sorrowful situations, philosophical thoughts, and the hero's suffering intensifies. Furthermore, the poet expresses feelings of pity in his heart for suffering people or natural phenomena caused by human suffering. For example, in the poet's poem "Horse Elegy", the poet expresses his pity for the horse that is suffering from a small sedge getting into its leg while galloping and playing in space.

Shabısqa qumartqan ǵarrı arǵımaq,  
Jeligip shılbirin úzdi de ketti.  
Doynaǵı qızǵanda arshıl jániwardıń,  
Qushaǵı keń dala dúbirlep ketti.

... taplap ósken jerdiń lala güllerin,  
ǵapılda súrnikti bir qıyaq tasqa.  
Jániwar sezdi me sońǵı demlerin...  
telmirer oqırandı batqan quyashqa.

Hám muńlı kózleri sonda móltiledip,  
qulınshaq gezlerin oylay basladı.

«Attı hadallayıq tirisinde», - dep  
jolawshı qanjarın qayray basladı...

The poem also has a short lyrical plot. In it, a lyrical digression is given in recalling the moments of the foal to further deepen the story and convey the state of the horse. The ending of elegiac poems is conveyed through loss or suffering. So, the event ends with the horse's death. Such elegiac depictions are found in the works of I.Yusupov in Karakalpak literature. In the works of B.Genjemuratov, one can find the smallest lyrical forms - couplets and triplets.

Two-line poems, like those of other Turkic peoples, have long existed in Karakalpak literature. However, the two-line poetic form, consisting of only two lines and expressing complete thought, emerged in our literature from the second half of the 20th century as an independent poetic work. Such forms are frequently found in Karakalpak oral literature. [2; 62-63]

In the works of the poet B.Genjemuratov, two twos, built on a free form, are encountered. They "Gúrji iyt" hám "Professor Kurbanbay Járımbetovtıń shákirtine tásellesi" songs on the theme. For example, Sennen qorıqpayman.

Ashshı dawısıńnan shorshıydı mıń adam.

In this case, through the metaphorical depiction of the Georgian dog, the main object reflected the image of some people who cannot see the development and achievements of educated people in our society. The poet skillfully used inversion, one of the figurative methods, to ensure semantic unity between lines and achieve aesthetic beauty in the content. Furthermore, this couplet is structured in a free form, with the first row consisting of six syllables and the next row of twelve syllables. Such artistically free-form couplets are also found in the works of S. Ibragimov. For example,

Basıńa jalǵızlıq kelmegey  
átirapıń jaynaǵan adam bolıp turǵanda.

In this, the lyrical hero's thoughts and conclusions are combined into two lines, forming a semantically unified sentence. The artistry of an idea is revealed through the application of inversion.

Thus, aphorisms predominate in two-line poems in lyric poetry. The themes of such poems are very broad, and they can reflect philosophical thoughts, love experiences, and the human psyche.

"Úsh" alǵan student dalada qalmas.

Ol direktor bolar, múǵallım bolmas...

In the content of this two-line work by the poet B.Genjemuratov, aphorisms and didacticism, built on philosophical thought, occupy a prominent place. At the same time, there's a hint of sarcasm in these two. That is, the fact that a poorly performing student cannot raise a child as a teacher is given in bitter sarcasm, saying that he will become a "director".

As a result of analyzing B.Genjemuratov's poetry, we have identified the following triads. In this case, the first three are constructed in a free form without rhyming:

Ya toba!

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Pushkinniń qanatında p rwaz etkenler  
Pushkinniń p rwazın  yreter emish!

In this case, the main attention is focused on conveying deep and concise content. In this life, the lyrical hero expresses feelings of dissatisfaction with something, anger towards someone, and anguish. Metaphors like "Pushkin's wings", "to soar", and "Pushkin's flight" are important in conveying the intended meaning figuratively and artistically.

G nalisań s ygeniń ushın –  
p tkil  miriń jandı jollarda.  
Atar tańıń – k l h m t tındur.

Thus, through these short lines, one can understand the inner spiritual state of a lyrical hero afflicted with the pain of love, whose entire life burns on the roads, and by transferring each dawn to the metaphor of ash and smoke.

In general, in B.Genjemuratov's poetry, couplets and triplets are considered a manifestation of the poet's high level of intellectual knowledge in ensuring the sharpness of thought and the artistry of content.

### The reflection of the fate of the people and nation in B.Genjemuratov's poetry

In the work of B.Genjemuratov, one can see works with a number of peculiarities, aimed at educating a person in the national spirit. Specifically, the reason B.Genjemuratov's poem "Mo'da Khan's Words or the Inscription on Chinese Silk" came to the forefront of public attention is that the author passionately celebrates the idea of defending the Homeland in this work, emphasizing the need to protect this golden land, inherited from us through the heroic struggle of our ancestors, like the apple of one's eye.

Features characteristic of B.Genjemuratov's poem can also be seen in his poetry. In this, the lyrical hero lives and cares for the fate of the nation, the peace and freedom of the people. He longed for Alpomish and Qoblan to be ready to defend the homeland. Furthermore, his poems emphasize celebrating virtues such as human dignity, courage, and humanity, thereby evoking a sense of upliftment in every reader.

In the poet's poem "Where are the heroes of this land?!" the idea of protecting the homeland and strengthening the peace of the people is skillfully conveyed through the inner turmoil and reflections of the lyrical hero. In this, the lyrical hero travels the world, searching for heroes who defend their homeland

Bezigip sibir-sibir G pplerden,  
bezigip n wbechi M pplerden,  
k kirek kerip turǵan,  
sawlat, k rik bolǵan,  
qaraqalpaqqa aybat berip turǵan,  
kettim Shilpiq qorǵanına –  
payıw – piyada.  
Silkinip qonǵan qıranday, uyaǵa

silkinip jettim.

Q lbimde sawal,  
sanmın d rt:

"Bul jurttıń batırları qayda ?!"

"Bul jurttıń batırları qayda ?!" [1; 51]

Thus, when the lyrical hero goes on foot to the Chilpiq fortress, the history of the Karakalpak people comes to mind. In it, the warriors annihilated the enemies who had invaded Chilpiq, protecting their native land. Therefore, the poet searches for heroes to defend the people in the Chilpiq fortress. The poet's anguish and reflections on the peace of the people and the fate of the nation affect the inner world of a person, calling them to awaken from their slumber

Silkinip oyanar bir eles.

Ruwımdı silkiler sol eles:

«Batırlar mın jıllıq ǵ plette.

Shayırlar bir  sirlik uyqıda...

Oyatıńlar!

Alpamıstı...

Sh yardı oyatıńlar...

Jalaladdin Manguberdi oyatıńlar!

Ernazar Alak zdi...» [1; 51-52]

In this, the poet's portrayal of heroism through the characters of Alpomish, Sharyar, Jaloliddin Manguberdi, and Ernazar Alako'z seems to inspire the people to be equally brave and strong.

At the end of the song, the lyrical hero's emotional state is conveyed, and he addresses the Aral Sea ecological problem, a pressing issue facing the state today. If the Aral Sea is not full, the people will conclude that they have no future.

Q lbimdegi sawal,

sanmın d rtlerim

sanmillion japıraqlaray sıdırlasadı,

sheksiz t shwishlerdiń d rwazasın ashadı:

- Mınaw  miwd rya tasıp turmasa,

anaw jetim Aral tolqıp turmasa,

Batırlar mın jıllıq ǵ pletten oyanbaydı –

Shayırlar bir  sirlik uyqıdan...

Oyanbaydı...

Poet's " giz d rya bitikleri" Included in the series "Qırıq  sir k mip ketken", "Mın  rkeshli t eler-sarǵısh qumlar", "Qum astında mın sandıq", "Debdiw", " zge bir qudaylarǵa", "Jeti babańnıń ismin ayt Jayhun", "Sh llegenmen p tin diydarińa", "Tay qulınday tebissen", "...altı aǵa ketip alısqa", "T rk babanıń q hari", "Qardıń basın qar alar", " yemgi T rkistannıń b gingi balları", "T sime enedi Baysın tawları", "Ata jurttan ayrılıp" and other poems, the theme of the homeland, specifically the fate of the nation, the peace of the nation, the unity of the people, courage and bravery, and feelings of love for their native land, are sung through lines that penetrate the human heart. In this, the poet's concern for the fate of the people is clearly felt. The poet grieves over the tragic fate of the heroes of the people who perished due to the lack of unity, treachery, and the deceit of enemies. The poet emphasizes that even

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today, ordinary working people often fall victim to injustice.

The poet's poem, beginning with "Today's Children of Ancient Turkistan", discusses the fate of the Karakalpak people and the entire nation. In it, the poet compares the present with past centuries.

Áyemgi Türkistannıń búgingi balları,  
tańlap mingendeyin argımaq az úyırde,  
kerilip jay tartalmas – ilenázik qolları,  
balıqkóz aqsawıttı toltırmas iyinleri.

Thus, in each line, the poet's attitude towards today's life, his feeling of pity, is reflected. Reflecting today's reality, they emphasize that the ecological disaster in our country is also linked to the fate of the nation, stating that no house can be built with pride like our ancestors, nor can the body be filled with the white armor worn by heroes.

Áyemgi Türkstannıń erteńgi balaların,  
alıp etip tuwǵanday alıp Ana joq,  
sherdiń júrek - bawırına jeriytuǵın kókirek,  
sherge sarıjay tartar bilek – shama joq.

In conveying his thoughts on the consequences of the ecological disaster, the poet utilizes the motifs of the "wonderful birth of heroes" from folk heroic epics, giving them poetic expression. In epics, when heroes are born, their mothers take a tiger's heart and expect a son. Thus, in popular belief, heroism is passed down to a child through the mother. Indeed, a healthy mother gives birth to a healthy child. The poet enriches the current ecological problem and the devastating impact of the Aral Sea tragedy on the health of mothers and children with his views on historical figures and epic heroes.

Áyemgi Türkistan – qashqashshı ǵarǵıday,  
bul áyemgi topıraq – qanı az Ana.  
Taylar at bolalmas uwızına jarımay –  
Alpamıs bolalmaydı záhárlengen bala.

Thus, these lines address the ecological problems in our country, environmental protection, the elimination of anemia among the population, and the birth of a healthy child.

Furthermore, the poet treats his native land and homeland with great respect, admiring its beauty and rich nature, asking for whatever pain is in his heart. For example, in the poem "Thoughts in the Rainbow":

Hár kimniń aqılıw-oyı  
Ózi mingen minber bolar.  
Eldegi shadıq, ǵamı  
Baxıtlı kúnler bolar.  
Sezimniń biyiginen  
Men saǵan qarap turman.  
Ne awır isiń bolsa  
Júregime sorap turman.  
Sen maǵan taj hám taxcan!  
Sen maǵan quyash, baxıcań!-  
Nókisim!

In most of his poems, B.Genjemuratov expresses his attitude towards socio-political situations, the future of the people, the fate of the nation, and

expresses feelings of pain through historical heroes and historical figures. "Bakhtiyar Genjemuratov has a unique way of expressing his thoughts. The poet strives to perceive the world in all its scale and content. He looks back at the history of patriotism, at the past and present of its culture. History makes him suffer. His poems, like many poets, are written in a rhythmless verse form, yet they fall into a certain rhythm. [2; 16]. Thus, in most of the poet's poems, his feelings and reflections on his homeland and birthplace are conveyed through historical events.

Xalqımnıń táǵdiri shatırash tasınday  
Talay Ǵayıpxannıń qolında ketken...  
Shóldiń tariyx atlı keń taxtasında,  
Aq taslar qara tasqa aylanıp ketken...  
Bawırım Orazan!...  
Bawırım Maman!...

Sahram,  
meniń sahram kónlim qumlaǵı  
quwırılıp atr misli quwırmash...  
Asirdiń qızǵını – Quyash ondaǵı  
Meniń de jaslıǵım – tutilǵan Quyash!...

Here, the poet's subject matter is broad. Fully utilizing the potential of poetry, it breaks the boundaries of time and space, connecting history with the concerns of the present. The poet uses the images of historical heroes G'oyib Khan, O'rozon, and Maman to convey his thoughts and reflections on the fate of the people. In this, one can observe the poet's attitude towards historical figures.

Furthermore, B.Genjemuratov skillfully utilized examples of artistic folk oral traditions, particularly the rich folklore of our people, in portraying the fate of the nation and its people.

Oral literature preserves the people's thoughts about the world, a collection of the best ideas that cultivate goodness, humanity, and justice. To embody these ideas in everyday life, all forms of art rely on folklore. In particular, fiction relies on folklore to gain ideological and aesthetic spiritual strength. Therefore, the study of the connection between literature and folklore is one of the most important issues in the literary studies of all peoples. Certainly, this issue is of particular importance for Karakalpak literature, whose folklore is highly developed and whose literature is formed in close connection with folklore.

In all the poems of the poet in the \*tolgov\* genre, his inner spiritual anguish, advice, and pity for the fate of the people are expressed. This situation is directly reflected in the poet's poem «Tolgov.» For example,

Jalǵız shapqan at júyrik,  
ózgeler júyrik bolmasa.  
óz úyirin úyirip,  
at bolarlıq taylardı  
qulınında shaynasa,  
jalaw jalın sıyırıp...  
Jalǵız shapqan at júyrik.  
(Jalǵızlıqtan saqlası!)  
Úyırde ósken qulındı

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úyiri asırıp-saqılasın.  
Táǵdırdıń qara tasları  
doynaǵınan qaqqasın.

The poet's reflection that no evil or fate's black stones should strike anything in life is conveyed in such touching lines as mentioned above. Furthermore, it embodies the characteristics of the \*tolgov\* genre, structured into seven to eight short syllables, making it easy to read.

Recitations are mainly divided into general recitations, historical recitations, and recitations with preserved authors. In B. Genjemuratov's poems, historical events are often celebrated, and the courage and bravery to defend the peace of the country and the homeland are celebrated. For example, in the poem «Berdaq Shoir's Epic Poem», «Due to the cunning of the khans, the Karakalpak warriors Begis and Mirjiq died of grief. Aydos biy, consumed by regret, was soon executed.

Ernazar alakóz de sheyt óldi...

This was all because the biys dragged the people everywhere, the batyrs dragged them everywhere, the wealthy acted according to their will, and no one came forward to make them stand up for their word, to act as judges and elders...

Through these lines, presented as an introduction, the history of the entire Karakalpak people comes to mind. It speaks of the unity of the people, the peace of the people, and the realities of the time.

Bolar eldiń balları  
birin biri "batır!" der.  
Bolmas eldiń balları  
birin biri "qatır!" der.  
Jaw quyılsa eline  
tuwısqanıń "jatım!" der.  
Námártte namıs bolmaydı-  
úsh kún ashqa shıdamas.  
Qan maydanda kisnegen,  
ǵarsh-gursh suwlıq tislegen,  
batırdıń mingen atın jer.

Through these lines, the lyrical hero falls into deep sorrow. That is, in a united land, there will always be peace, and if people and heroes unite to save their homeland from encountering enemies, there will never be peace in a land without unity, they will only live thinking about destroying each other. In such a situation, the disintegration of the people, and the need for a leader to maintain unity and harmony in any nation to prevent this, is effectively conveyed through the lyrical hero's following sorrowful feelings.

Eldiń kátqudaları  
danalıq ece basınan,  
el ketpeydi qasınan,  
jolinan taysa eger de  
jurtın urı-sayaǵı  
shıbın jannıń ǵamında  
batırın atıp sırtınan  
jigitlik ardı satıp jer.

Bult bolmay jel bolmas,  
jawın jawmay kól bolmas.  
Mınsan biyden ne qayır,  
sanmın mártten ne qayır,  
qátquda bolmay el bolmas!...  
Xalqım-aw, saǵan ne boldı?!  
Namısın jawǵa jem boldı...  
Mın qıyaldıń dárbeni,  
qayda júrerin bilmey  
Berdaq muńǵa batıp júr...  
Berdaq muńǵa batıp júr...

Thus, in these evocative lines, the poet skillfully utilizes the \*tolgov\* genre in folklore, conveying the image of the era in which Berdaq lived. In it, the fate of people who suffered from divisions and discord among the people is skillfully narrated through the lyrical hero's inner emotional experiences and feelings of pity.

Furthermore, the poet's poem titled «Snow Takes Snow's Head», written in the form of a terme-tolgau, highlights the issues of humanity, humaneness, freedom, and conscience. For example,

"Qardıń basın qar alar,  
xannıń basın xan alar".  
Ruwhı qul bendeler,  
tegi shiyki, qam bolar.

"Qardıń basın qar alar,  
xannıń basın xan alar".  
Ashlıqta qol jaymaydı,  
Beglik attan túspeydi,  
tegi-hasilzadalar.

In these lines, the lyrical hero asserts that spiritually immature individuals are still underdeveloped and cannot find their place in society. Furthermore, he calls on people to become well-rounded individuals, believing that those who achieve everything in life through their own labor and strength will always prosper.

Thus, through the skillful use of folk \*terma-tolg'ov\* in his poetry, the poet achieved ease of reading and a high level of impact on a wide audience. Furthermore, it can be seen that he effectively conveyed profound philosophical and didactic ideas such as peace in the homeland and national unity to future generations. This undoubtedly indicates the poet's profound knowledge of Karakalpak folklore.

And the poet's own «Shıǵısta oyanbaqta dáw uǵlan-Turan», «Bizler bes tuwısqan», «Túrkan oyda "Jeti qaraqshi"ǵa telmirip», «Nuw payǵambardıń aytqanı», «Jaqsıdan-sharapat, jamannan-apat» Many of his songs are based on folklore legends and folk traditions. It is known that they performed several artistic and poetic functions in a literary work: Firstly, they played a significant role in figuratively conveying the lyrical hero's thoughts, inner feelings, and the people's worldview. Secondly, they also served an artistic function in deepening the content of the work and conveying the author's idea to the reader.

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In short, in B. Genjemuratov's poetry, the lyrical hero lives with concern for the peace of the people and the fate of the nation. Furthermore, through the use of folklore examples, one can see the free expression of any content and thought, as well as the broad scope of its impact on the reader. Through this, we see the poet's profound knowledge of folk oral traditions and his skillful use of them. At the same time, through the depiction of historical figures and events in their poetry, they conveyed feelings of love and patriotism for their homeland.

### Reflection of the theme of love in the poetry of B. Genjemuratov

In Karakalpak literature, B. Genjemuratov's intimate lyrics have several unique artistic and formal characteristics. Especially his intimate lyricism in a poetic form arouses interest in every reader.

B. Genjemuratov's intimate lyrics are distinguished by their artistry, the lyrical hero's sensitivity, and the skillful use of artistic devices in character creation. In particular, artistic lines expressing the inner feelings of the lyrical hero inevitably affect the reader's inner world. The poet's intimate poems are not just empty words like "I burned, I loved". It illuminates the lyrical hero's inner turmoil and pure love with unique colors, stirring the reader's emotions. This testifies to the poet's originality and eloquence. The creation of intimate lyric poetry has its own laws. No matter how intimate she is, she doesn't like completely naked words. On the contrary, such words spoil delicate words, turning them into unnecessary, even disgusting possessions. In each of their works, they control their emotions, wrapping their world of thoughts tightly, and painting it with artistic colors. This is a sign of the maturity of his poetry [1; 6].

By genre, love lyrics convey the crystal-clear feelings emanating from the heart of the lyrical hero. The lyrical hero's heartfelt feelings arise on the basis of natural human love, and they acquire ethical and aesthetic qualities as a result of external worldly influences, specifically the influence of social orders, customs, and life norms, as well as the result of experiencing the world. In love songs, the lyrical hero is overwhelmed by feelings of sincere love, a natural human quality. [6; 41]

Poetic works that embody such genre characteristics constitute the vast majority. For example "Bayağı baǵlardıń gúlleri – ózge", "Jáne muń, saǵımış... jáne eski dárt", "- Allo... Bul kim? ... 24 – 14!", "Álwidah, perishtem, álwidah!", "Bunsha shóllegenseń báharge, janım", "Janım-aw... qálbińdegi hásiwet, shadlıq", "Men seni izledin tańnan. Tappadım", "Qaylardadur sınısǵan aqquw" and other poems can be considered remarkable examples of intimate lyricism.

The intimate lyrics of the poet B. Genjemuratov are aimed at reflecting the beautiful facets of the

lyrical hero's inner world, his sufferings and pains. The poet's lyrical hero is depicted as loyal to his beloved.

Janım-aw... qálbińdegi hásiwet, shadlıq  
ne ushın mólt-mólt etip kózińe uradı?...  
Sol payıt júregimnen jalın aǵılıp,  
tamaǵımda tas túyin tıǵılıp turadı.

Janım-aw... qanshalıq qattı bolmayın.  
Bundayda ózimdi tutıwım qıyın.  
Ayralıq qosıǵım aycań hárdayım  
Qarań qalǵır "tastı jutıwım" qıyın...

The lyrical hero's inner longing and love for his beloved are skillfully depicted through hyperbolic imagery.

Furthermore, the poet uses unique methods and forms to convey intimate lyricism, enhancing its impact on a wider audience. For example, let's take the poet's following lines:

Júregimdi saqlap edim qol jetpes qarlı shıńlarda,  
Ay, sen perdeńnen sıǵalap, qálbimdi muzsız,  
qarsız ettiń.

Tákabbir "boycoviy qorazday", Gúldi mensinbes edim,  
Beklik qanatlarımı julıp, qorazdı pársiz ettiń.

"Ishqı perisine bende bolǵannan ólgenim jaqsı",  
Desem, qayshıń menen qıl arqandı kesip, darsız ettiń.

Jónińe júrmediń sen. Úrkittiń menlik Aqquwardı,

Kelseń-kel Sánemlerdi mennen bezdirip, yarsız ettiń.

Pákize, uyalshaq suwıpıday músápir Baxtıyardıń Qolların, jolların, kózlerin hám ózin arsız ettiń!...

These two-line poems have unique characteristics. The artistic devices used in it reflect the inner spiritual world of the lyrical hero, that is, the poet, afflicted by the pain of love. By comparing himself to a thoroughbred rooster, the lyrical hero states that he is a man who does not bow to love, and by comparing himself to a Sufi, he says that he is a child who has never tasted anything. Furthermore, the antithetical imagery used in the poem enhances its poetic beauty.

Another characteristic of B. Genjemuratov's intimate lyrics is their poetic form. The \*muashshaq\* is a long-established poetic form in the literature of Turkic peoples.

The poet's poem "Lost Me", written in the form of a muashshaq, expresses love, the inner turmoil and feelings of the lyrical hero. The song's compositional structure is captivating, with the name of a girl named «Qalligul» appearing in the capital letters at the beginning of the lines.

Qalı bar gúldi kórip, sabır-qarardı joǵalttı,  
Az-maz uyatım bar edi, uyat-ardı joǵalttı,

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Lábinde kúlki kórip, qam sút emgen bende boldım,

Lal boldı húsn-kórkiñe, úyge sapardı joǵaltım,  
Ishqında dárwish boldım, «Cheremushka»  
arasında,

Gáp aytım aljı-buljı, ózimde bardı joǵaltım,  
Úyinniń qapısın mezzgilli-mezzgilsiz qaqqım  
keler,

Lap emes, shın sózim, Májnún Baqtıyardı  
joǵaltım ... [1; 69]

Reading the title of the work, one might think the lyrical hero has lost their beloved. However, upon reviewing the text, we understand that it is in a different direction. Here, the lyrical hero is the poet himself. The gradual intensification of his love for his beloved is presented in a gradational style. The lyrical hero first speaks of losing his patience, shame, home, everything he has, and finally, even his human self. ("Lap emes, shın sózim, Májnún Baqtıyardı joǵaltım..."). Thus, the poet's intended thoughts, namely the feeling of love, are revealed in conjunction with the beauty of the external form and the expressiveness of the content.

Furthermore, lines expressing such feelings of love are also found in the poem by the poet S. Ibragimov, which begins with "If I search, I won't find it in the garden". In it, the lyrical hero laments the absence of his beloved, saying, «I used to be many, but today I am thin.»

Juldız jerge túser - qasımда joqsań!  
Samal qayıp eser - qasımда joqsań!  
Taǵı qara nóser - qasımда joqsań!  
Men burın kóp edim, men búgin azban.

Endi dáregińdi qaydan tabarman –  
endi júregimde qaladı árman –  
endi men samalǵa sıbırlanaman –  
men bir alıslarda umıtilǵan sazban.

The poet's poem titled "Let Your Coquettish Laughter Remain", in which the name of a girl named Genjaxon is mentioned, is also written about love. For example,

Gúlge jarasadı ashılıw, jaynaw –  
Erkem, kúlki-shadlıq Sizge jarasar!  
Náyleyin, múmkin emes Aydı jasırıw...  
Jigitler «waaq!» desip Sizge qarasar!..  
Erkem, bir kúl qáne, Quyash nurınday!  
Xanań tańǵı Gúldey jawdırap tursın!  
Aq maral sıyaqlı keril burıńıday...  
Nazlı kúlkiń qalsın, basqası qurısın! [1; 102]

The song is full of inner feelings. In it, the "vapor" of love in the lyrical hero's heart seems to be spreading around. Because for the lyrical hero, whose inner feelings are burning with passion, the feeling of love, the beauty of his beloved, and a joyful smile are above all else (...» Let your coquettish laughter remain, let the rest perish!).

In the poet's work, the expression of strong intimate lyrical feelings through landscape lyricism

enhances its impact. In it, he imbued the seasons of spring, summer, autumn, and winter with various meanings, conveying them with poetic skill. For example, the poet portrays autumn as a symbol of both separation and longing, reflecting the lyrical hero's inner turmoil of love. For example,

Gúz, saǵan usamayman.  
Seniń saltanatlı qádemlerińde,  
ayralıq, ayralıq, ayralıq...

Gúz saǵan usamayman.  
Biraq júregimde –  
saǵınısh, saǵınısh, saǵınısh...

In summary, the poet masterfully conveys such deeply inner, hidden, yet elevated and beautiful feelings of love in the lyrical hero's heart through a unique artistic form. In terms of content, it's intimate lyricism, while poems based on \*mushak\* express B. Genjemuratov's unique poetic mastery - his ability to combine the depth of content with the beauty of form.

### Artistic devices and their artistic function in poetry

In B.Genjemuratov's work, one of the internal formal features in conveying content artistically is the skillful use of artistic means.

The theoretical foundations of literary devices have been studied by many scholars. However, the artistic devices in B. Genjemuratov's poetry have not yet been fully explored. In particular, in B.Genjemuratov's poetry, the figurative meaning of words and phrases is frequently encountered. However, in literary studies, this shift in the figurative meaning of a word is referred to by the term "trop". Vocabulary is the use of words in a literary work not in their literal meaning, but in a figurative sense to express something. In literature, tropes have various forms, such as metaphor, metonymy, synecdoche, allegory, litotes, and symbols. [7; 219]

In his lyrics, B.Genjemuratov skillfully utilized similes, considered the simplest form of tropes, to emphasize their significance. An analogy is the comparison of one object with another in a literary work. In literary works, comparisons are usually formed in the Karakalpak language by adding suffixes like -day, -dey, -tay, -tey, etc., and create imagery, expressiveness, and depth of thought. [7; 200]

Kóz aldımда  
quwırmashtay quwırılǵan qumlar  
shashlıp ketedi –  
qálbimde pikirler shashılar:  
qaraqalpaqtıń ótmishi dep úyrenilgen jıllar  
ustalarsız qalǵan gerbishler yańlı,  
qıyalımда... jıǵıla baslar...

In this free-form poem, the poet sorrowfully depicts the fate of the people and their history. "Fried Sands" - this line is hyperbolic, comparing the harsh events in the history of the Karakalpak people and the tragic fate of the people to roasted sands.

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qaraqalpaqtıń ótmishi dep úyrenilgen jıllar ustalarsız qalanǵan gerbishler yańlı,

In these lines, the poet laments the past history of the Karakalpak people. The comparison of the Karakalpak people's past to bricks laid without masters seems to indicate that history was uneven.

Metaphors are also productively used in the poet's poems from the \*muashshaq\* cycle. For example, in the poem "When Will You Come?" given under the title "Thank God..." in this section, comparison is used appropriately to enhance the depth of meaning:

Qudaǵa mıń qatle shúkır, razıman!  
Appaq qollarına qollarım tiydi...  
Shuǵlaǵa bólendim ishı sazınan,  
Ayday júzińizge láblerim tiydi...

Here, the poet uses the suffix "-day" to compare the beauty of the girl's figure to the beauty of the moon. This is one of the traditional descriptions frequently used in epics and Eastern poetry to depict a girl's beauty.

In the "Kumusay" collection, the beautiful girl's delicate lips resembled cherries. For example:

Gúller gózzal emes, lábleriń gózzal!  
Úlbirep turıptı, shiedey qızıl.

In this, the poet expresses the lyrical hero's inner feelings for the beautiful girl through artistic means. In the poem, the poet compares the delicate nature of the depicted beautiful girl to the bright red color of cherries.

In general, analyzing metaphors in the poet's work, we witnessed their frequent use. For example, the frequency of using similes in «Selected Works» is as follows: 71 words are formed using the suffix «-day», 39 words using the suffix «-dey», 18 words using the suffix «-tay», and 8 similes using the suffix «-tey.» Four similes were formed by adding the suffix «-day» to the word «tal.»

"Tallarday mǵilgen saratandaǵı",  
"Májnún talday ǵamgún ómiriń",  
"japıraǵı tógilgen talday ármanlım",  
"Gelleklengen talday toqalaq úmitler".

By adding the suffix «-dey» to the word «gul», the following similes are formed. For example,

"Lábleri lala gúldey – posalarǵa saqıy. Biraq ta,"

"Xanań tańǵı Gúldey jawdırap tursın",  
"Gúllerdey ashıl, Samal",  
"Gúldey láblerinen súer edim men!",  
"Gúldey siynesiniń iysine toyıp",  
"Janı názik gúldey, al biraq".

At the same time, we witness that similes in the poet's work are frequently created through the use of the adjectives «like», «like», «like», «in the same way», «for example», «like», and «like». For example, 23 similes are formed through the suffix "yanglı", 5 similes through "siyaklı", 3 similes through the auxiliary words «kibi», «masalan», «öxshar», 7

similes through the suffix «misli», and 1 simile through the word «taklit».

Through metaphors, the poet expresses the inner turmoil and life journey of the lyrical hero, sometimes conveying the feelings of suffering from love, and sometimes the poet expresses their philosophical thoughts through metaphor.

For example;

Kónilim názik edi,

Al sen tas ediń.

Shıraylı gúl ediń tikeniń menen!

"Nazıń at kótermes"....

óziń más ediń.

Sen bir sherbet ediń záháriń menen!

(117-bet)

In this, the poet gives life to natural phenomena, comparing winter's harsh cold and frosty belly to a beautiful girl, and conveys her beauty and stubbornness through metaphorical descriptions like «you were a flower, you were a stone, you were a syrup.»

Regarding this artistic function of metaphor, the Turkmen literary scholar R. Rejebaev wrote: «In the experience of lyric poetry, in the history of poetry, there has never been and will never be a lyric without metaphor, and without metaphor, lyrics cannot have lyrical meaning» [8; 13] (This idea is taken from the scientific work of B.Genjemuratov). This scientific thought demonstrates that without metaphor, lyrics cannot possess lyrical beauty or lyrical meaning.

Metaphors, by their nature, are close to similes. In metaphor, the comparison of two objects reveals the object figuratively and authentically. Therefore, in some scholarly works, metaphors are sometimes referred to as «hidden similes» or «short similes.» However, similes and metaphors have their own unique characteristics. In any complete simile, there must be four elements: the similar, the compared, the similar characteristic, and the affixes of the simile. In metaphors, there is only one of these elements [9; 131]. Moreover, while a simile is often used literally, a metaphor is used figuratively. For example,

Gúlge jarasadı ashılıw, jaynaw –  
Erkem, kúlki-shadlıq Sizge jarasar!  
Náyleyin, múmkin emes Aydı jasırıw...  
Jigitler «waq!» desip Sizge qarasar!..  
Erkem, bir kúl qáne, Quyash nurınday!  
Xanań tańǵı Gúldey jawdırap tursın!  
Aq maral sıyaqlı keril burıńıday...  
Nazlı kúlkiń qalsın, basqası qurısın! (102-bet)

In the poet's poem «May your gentle laughter remain», «gul» is used as a simile, involving the four main elements.

1. equalizing object, that is, the object being equalized.

2. an identifying object, that is, a similar image - a flower.

3. the similarity between comparative and analogous things is that they are juxtaposed.

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4. comparison suffix - dey.

In the following lines, the word «flower» is a metaphor. For example,

Sıñq-sıñq küldi: “Men bir gülmen.  
Bağdı qynar şól...- dedi-  
Qorqsañ urı bolıwdan sen,  
Jigit bolmay ól...”- dedi (134-bet)

In this first poem, the lyrical heroine, by comparing herself to a flower, figuratively conveys certain characteristics: her delicacy and beauty.

In literature, metaphor is used to vividly and effectively depict objects and events. A work of art is an artistic reflection of the phenomena of life, society, nature, and the spiritual world of man. Metaphor plays a crucial role in conveying these phenomena, ensuring the artistry of the work, and revealing its depth of meaning. Metaphor is one of the actions that ensures the value of a literary work. Appropriately chosen metaphors can fully and artistically convey the creator's intention, ideas, and thoughts. For example:

Baxtıyarda qosıq joq. Qaraqalpaqtan jir ketti...  
“Tiriler”den túnilip, bul dúnyadan tiri ketti...  
Endi ğana er jetken Poeziya jetim qaldı.

Shayırlardı jılatıp Ullı Ibrayım piyrim ketti...  
(30-bet)

Here, poetry is one of the genres of Karakalpak poetry. At this point, B. Genjemuratov, to artistically convey that the poet Ibrahim Yusupov was the sultan of Karakalpak poetry, a great figure, compared the poet to poetry and verse, figuratively depicting the isolation of Karakalpak literature without him.

A metaphor is the modification of a word's meaning to enhance the clarity and beauty of the depicted object by comparing them to similar objects or phenomena, thereby enhancing the artistry of the meaning.

Aqılma bağımbas júrek.  
Sezimlerim - lawlağan jalın.  
Shólistanğa bir bulaq kerek.  
Tún qoynına juldızlı sağım.

Sen – jumbaqsañ. Sheshilmeysen hesh.  
Bul báhardıñ qúdiretimeken?!  
Gúl bolsañ sen quyash ushın ós,  
Soqpaqlarda bolmasın tiken. (141-bet)

In these lines, the lyrical hero's inner turmoil, longing for his love, and feelings of affection are conveyed through beautiful, artistic, and impactful metaphors. The lyrical hero likened his feelings to a blazing flame, himself to a withered desert, and his love to a mysterious riddle. Furthermore, the lyrical hero's perspective on love, joy, longing, regret, and inner emotional state are effectively conveyed in the following lines through remarkable examples of metaphor.

Qulıña ishıqıdan basqa ne dárkar?!  
Lapıldap júregime eneseñ sen.  
Jalınlar ummanına aylanar Baxtıyar!  
Qálbimdi dumanlatıp sibirlysañ sen:

- Men ele dawıl bolıp kelemen erteñ...  
Men ele jawın bolıp kelemen...

Sen – ertekseñ. Men bir náreste.

Túnlerde qushağında buyıqtırasañ.  
”Er jettim, bir posa alayın” desem,  
óptirmeysen ushup turasañ,

Jáne sibirlysañ júregime:

- Sen bala delbe bolıp keteseñ erteñ...

Sen bala delbe bolıp keteseñ...

The lyrical hero's inner state, the intensity of their longing feelings, is conveyed through the metaphor “ocean of flames”, and the uncertainty that has gripped their heart is conveyed through the metaphor “make my heart foggy”. Furthermore, the metaphors used in the poem, like “there's a storm”, “there's rain”, “you're a fairy tale”, and “I'm a baby”, play a significant role in creating imagery and conveying inner form. Every aptly chosen metaphor in his works can fully and artistically convey the creator's intention, the ideas he put forward, and his thoughts.

Such metaphors are figuratively used in the lines of S. Ibragimov's poem, which begins with “I need fairy tales”, to express the inner turmoil of the lyrical hero and the feelings of longing for his beloved.

Erteklerge mıtájben.

Kelermiseñ

qarañğı túnimdi urlağan

nárestem? [10; 39]

Furthermore, unique metaphorical descriptions can be found in the poet's poetry. For example:

Señler qozğaladı...

Qıstın señleri.

Dáryanıñ ağısı-

Ruwhimniñ ağısı.

Soñğı appaq qarğa kómiledi

qálbimniñ mart ayı.

qálbimniñ apreli... (122-bet)

The metaphors «the flow of my soul», «the month of March of my heart», and «the April of my heart...» used here are intended to convey memorable moments in the poet's life.

(... Ayağım – Batista,

Basım – Shıǵısta,

Júregimde – Saratan...)

Siyasat – duwtardur,

onıñ tarların

talǵamsız urıp tur neytron sawsaqlar.

(Shayırdıñ monologı)

Here, «Saratan» is a form of landscape lyric poetry, representing the hot, bustling nature of our land during a single season. Here, «Saratan» is used as a metaphor to express the lyrical hero's thoughts on society and life that are burning in his heart. A metaphor reflecting this meaning is also found in the lines of A. Aripov's poem «Saratan».

In the works of B. Genjemuratov, we see the successful use of metonymy. Metonymy is one of the

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means of depiction. Illustration based on the figurative meaning of words. In metonymy, the depicted object or event is described under a different name. For example “The pot is boiling”. Actually, it's not the cauldron that's boiling, but the food in it. I burned the cauldron. It means the cauldron won't burn, but I lit the firewood inside it. The city is sleeping. It's not the city, but the people there are sleeping [7; 132-133]. For example, in B. Genjemuratov's poetry, metonymy serves to deepen the meaning and reveal the poet's thoughts.

Señler qozğaladı –  
Señlerge señler qağısıp.  
MENler az qaladı –  
MENlerdi MENler shabısıp (s.4)

Thus, the metonymy «I» in the poet's poem «Abirji» refers to the people who compete and clash with each other in life.

Qayıp tepken Jayhunda bul  
Joğımdı men izledim.  
Qálbimde dárt, múń sağımısh,  
Tereńlikti gizledim.  
Biraq Shúńgil degenlerim  
Sayız shıqtı oğada... (s. 32)

Here, the lyrical hero is sought in this life. The figurativeness and conciseness are ensured by replacing the words «deep» with the properties of the difficult and heavy objects he discovered, and «shallow» with the properties of the simple and light objects.

The poet's poem titled «Javob ber» (Answer), which originates from the name Guliston and is included in the «Navruz shamallari» (Winds of Nowruz) series, is humorous. Through the metonymy «Satan the mustachioed, mustachioed, and bearded», several people of different ages who are in love with a girl are re-named. Through this metonymy, the lyrical hero (poet) jokingly expresses his inner feelings to the girl whose name is hidden.

Gúlábi qawınday shireń tamıp tur,  
Úh! Erniń, kózleriń ne dep janıp tur?!  
«Lawlap órtenbeske qoymaspan!» dey me,  
İsen, kúlim qaldı... Bul shin-anıqdur.  
Sáteń murthı, murcız hám saqallılar,  
Tolı goy átirapıń, olar nağıp júr?!  
Arsız sağal yańlı jalańqaya bir zat,  
Náyleyin, qálbimde qańsılap shawıp júr...

Moreover, one of the tropes effectively used in the poet's work is the epithet. An epithet is an attributive term used to describe the quality or qualities of objects and structures. An epithet is the most frequently used form of artistic depiction through which writers and poets highlight the most striking characteristic of a character or phenomenon, thereby presenting it more vividly.

Waqıt qayrağında tas sawsaqlarım,  
polat pánjelerge aylandı búgin –  
qara mármner sınar sığımlarımında,  
Gúllerge qonıwǵa qorqaman, endi.

In this quatrain itself, along with epithets, metaphors, symbolic imagery, and hyperbole are used. Through epithets like «stone fingers», «steel claws», and «black marble», the poet vividly portrays the lyrical hero. Through the use of epithets, the poet draws the reader's attention to one or another characteristic of the depicted person or event, evoking a strong feeling in them.

“Pinhamı saqlaysañ miywalarıńdı,  
ashkóz sezimlerden, otlı názerden.”  
“Altın hám hinjili kewil sarayım,  
muzlı tınıshlıqtıń saltanatında,  
samsaz...”

Thus, epithets like «greedy feelings», «fiery gaze», «a golden and pearl-filled palace of the heart», and «ice-cold peace» in these lines enhance the poetic beauty of the poem.

Kúnbatıstan kelgen bultlar,  
jiyde aǵashın “jımlı” eti,  
sağımıshstan gúlin sarǵaytıp,  
japıraqların qul eti.

Túsinbeydi dártın heshkim –  
qara bulttıń aqlı lal.  
Egil-tegil hárkún keshte,  
bultlar negedur jılar?!

In these lines, the poet breathes life into the phenomena of nature, parallelly depicting the inner world of the lyrical hero, burning with the pain of love. So, they used animation using artistic means. Animation is a form of metaphor. Animation is a means of depiction that occurs by transferring human characteristics to inanimate objects, natural phenomena, animals, or birds.

The personification of inanimate objects with a soul is used with special poetic skill in the lyrics of B.Genjemuratov.

In the poem «Romance of the Willow», «autumn's natural processes - willow leaves turning yellow and falling to the ground, winds blowing, and willow's free dance - are skillfully and figuratively depicted by animating natural phenomena.

İńıdaydı jalańash tal,  
samallargá aldangan,  
nárwan edi sahibjamal  
qız sıyaqlı sallangan.

Goshshaq Gúzdıń ruwhı bálent,  
tamsandır'ıp sawlatı,  
bul jas taldıń erkin biylep,  
japıraqların sawlattı.  
Gálet – Gúzdıń háreketi!  
Taldı muńlı eti ol.  
Jalańashlap erketip,  
kiyindirmey ketti ol... [1; 98-99]

In this case, the willow's groaning is a phenomenon characteristic of human psychology. The poet compares a young willow to a beautiful maiden. In the lines of the poem, «The naked willow groans,

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deceived by the winds”, the sorrowful image of a girl deceived in life comes to mind. However, G'oshshoq O'z's actions depict those who harm people's hearts through their own «winds”. Therefore, there are specific ways to make any work artistic. At this point, the poet skillfully uses animations to convey the emotional turmoil of people in the image of a «naked willow».

Animation is used in literary works for the figurative expression of thought. The transmission of human-like feelings and thoughts to unconscious beings and objects is one of the characteristics of animations. In B. Genjemuratov's poetry, such animations are depicted in parallel to convey the inner emotional turmoil and feelings of longing in the heart of the lyrical hero.

Duwtarın ińrandı, dártn men sezdim.  
Ol muńlı gúmbirlep basladı sózin:

Ne ushın duwtar qıp jarattıń, Alla?!  
Ada bolmas dártke sen shattıń, Alla!

Meni jigit etip jaratqanıńda,  
Yoshlı qumarlıqlar janıp qanımda,

Gúldey láblerinen súer edim men!  
Pútkil ómirim janıp-kúer edim men!... [1; 136]

Thus, in these lines, the dutor possesses both inner feelings and thought inherent to humans. He (the dutor player) wants to become human, to kiss his beloved's flower-like lips, to burn with passion throughout his life. Enhancement enhances the artistry and expressiveness of the image in poetry.

In general, artistic devices in B. Genjemuratov's poetry, serving as the foundation and «soul» of the poem, are used to artistically deepen the content of the poem and convey it to the aesthetic taste of the readers. This, of course, testifies to the poet's eloquence.

### The relationship of artistic devices to content in B.Genjemuratov's lyrics

In a literary work, especially in lyrics, the role of artistic devices in conveying the content of the work is paramount. Poets reflect the diverse experiences of the human psyche through artistic depiction. Artistic techniques ensure the beauty of the internal form and enhance the emotional impact of the work.

In a work, the function of form in conveying meaning is also realized through artistic methods. With the help of figurative language, a skilled orator achieves the ability to emphasize their intended message and place particular weight on it. The ways and methods of transforming lyrical experiences, life, social, and natural phenomena into artistic reality are considered methods of depiction.

B.Genjemuratov's lyrics are distinguished by their mastery in conveying philosophical, didactic, and truthful perspectives on all phenomena and events

in this world and the social environment. The poet effectively and skillfully employed artistic devices in conveying such profound ideas in their works.

In this section of our work, we will discuss the artistic methods of depiction in B.Genjemuratov's lyrics, the role of figures in deepening artistic meaning, and the artistic function of the parallelism, antithesis, gradation, and repetition used in it.

B.Genjemuratov's lyrics became very colorful. In it, a person's various actions in their inner world, their worldview, and inner turmoil are conveyed in a unique way. To convey such inner feelings, the poet makes extensive use of parallelism.

Biyiklikti ólshep atırmız,  
Tereńlikti ólshep atırmız,  
Ólshew múshkil eken Keńlikti.  
Awır zattı ólshep atırmız,  
Jeńil zattı ólshep atırmız,  
Saqlay almay teppe-teńlikti...  
“Awır zatlar shúmer tereńge,  
jeńil zatlar aspanlap keter.  
Bul keńlikti mensinbegenler  
Keń etikte aqsanlap óter!...” [1; 89]

.....

Parallelism is the constant interaction and coexistence of two phenomena or actions. In poetics, the arrangement of parts of a language element within a text in a similar or semantic order, i.e., a poetic method. Parallelism is used to accurately, effectively, and artistically depict events, phenomena, and emotions. Furthermore, by depicting events in parallel, the author achieves sharpening and clarifying their intended message.

In the poem «In the Zoo”, the poet uses a parallel depiction of the behavior and appearance of animals inside an iron cage.

Temir tordıń ishinde – ayıw,  
Temir tordıń ishinde – qasqır,  
Maymıldiki - báhá qol jayıw.  
Kiyiklerdiń kózinde jas tur...  
Jaca - temir, súense – temir...  
Mush kórseter “batır maymıllar”...  
Temir menen qorshalǵan ómir  
Tórt múeshli temirdey jıllar -

One of the frequently used artistic devices in B.Genjemuratov's lyrics is antithesis. Antithesis arises when events, images, and concepts are strictly contrasted in a literary work [7; 18]. Antithesis reflects the features of two or more phenomena by contrasting them with each other. Antithesis is often formed through antonyms. For example, in the poet's poem «Sawal” (Question), the lyrical hero's worldview and thoughts are conveyed through antithetical statements in the form of rhetorical questions.

Hayranman. Kózdiń taǵdiri – kúlmek, jılamaq.  
Al, lábler biyopaday tuyıladı maǵan.  
Ómirim – aǵıp atırǵan dáryadan ibarat.  
Sezimniń shıńlarıman baslanar saǵam.

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Bizler – aytilmağan därtli jırdaymız.

Delbemen bir nárseni, biraq bilmege:

“Kózde jas qalmağansha nege jilaymız?!”

Kózden jas aqqansha kúlemiz nege?!” [11; 12]

Here, the lyrical hero asks, «Why should we cry until tears remain in our eyes?! «Why do we laugh until tears flow from our eyes?!» The poet's question seems to find its solution in the following lines. For example,

Sanmın hikmetlerdi oqıp uqtım men,  
Gidir – budır qosıq toqıp uqtım men –  
Kózimde jas qalmay jılap túsindim,  
Kózimnen jas ağıp kúlip túsindim:

“men erte kelippen mına dúnyağa,  
Men keshlew kelippen mına dúnyağa...” [5; 25]

The antitheses created through the antonyms «crying» and «laughing», «early» and «late», are reflected in the lyrical hero's philosophical thoughts about this world.

Antithesis serves to reveal the depicted object with its internal contradiction and to vividly portray events and phenomena. Ensures imagery and aesthetic impact in the work.

“Jaqsıdan - sharapat, jamannan - apat” –  
birew pútinleydi, birew buzadı.

Keshegi húr dúnya – búgin alasad,  
Erteń bulttı súygen tawlar tozadı. [5; 51]

The poet depicted aesthetic categories such as «good» and «evil» in an antithetical style. The qualities of a good person and a bad person are skillfully contrasted.

In general, the antithetical method is frequently used in the poet's poetry to enhance the impact of philosophical reflections on life.

### Conclusion

Analyzing the genre and artistic features of B.Genjemuratov's lyrics, we came to the following conclusions:

- B.Genjemuratov is an innovative poet. He brought many innovations to Karakalpak poetry. Specifically, it expanded the genre possibilities of contemporary Karakalpak poetry, refined methods of creating artistic imagery and form, and acquired a unique style in word formation. The vers libre and muashshaq are one such genre exploration in the poet's poetry. In this, the poet creates unique images through skillful poetic language and artistic devices, clearly demonstrating the uniqueness of the inner form in the poet's works;

- B.Genjemuratov's work is distinguished by its formal diversity. It reflects poetic skill, literary connections, and the influence of world literature. Because in each of his poems, the poet skillfully utilized the possibilities of language, enhancing its (the word's) impact. Because the poet depicted his inner spiritual world in poetic lines, deeply connected with the realities of life. They also translated remarkable examples from the treasury of world

literature into the Karakalpak language, comprehensively developing their creative work. As a result of the influence of Western and Eastern literature, one can see the diversity of form and content in the poet's work;

- Based on their genre characteristics in terms of external form, we have identified the existence of genre forms in the poetry of B. Genjemuratov, ranging from the smallest genre forms to those found in our literature today, which have reached us through synthesis;

- Poet's “Ógiz dárya bitikleri” Included in the series “Qırıq ásir kómip ketken”, “Mın órkesli túeler-sargısh qumlar”, “Qum astında mın sandıq”, “Debdiw”, “Ózge bir qudaylarğa”, “Jeti babańnıń ismin ayt Jayhun”, “Shóllegenmen pútin diydarına”, “Tay qulınday tebisken”, “...altı ağa ketip alısqa”, “Türk babanıń qáharı”, “Qardıń basın qar alar”, “Áyemgi Türkistannıń búgingi balları”, “Túsime enedi Baysın tawları”, “Ata jurttan ayrılıp” and other poems, the theme of the homeland, specifically the fate of the nation, the peace of the nation, the unity of the people, courage and bravery, and feelings of love for their native land, are sung through lines that penetrate the human heart. In this, the poet's concern for the fate of the people is clearly felt. The poet grieves over the tragic fate of the heroes of the people who perished due to the lack of unity, treachery, and the deceit of enemies. The poet emphasizes that even today, ordinary working people often fall victim to injustice;

- Through the use of folklore traditions in B.Genjemuratov's poetry, one can see the free expression of any content and thought, as well as the broad scope of its impact on the reader. Through this, we see the poet's profound knowledge of folk oral traditions and his skillful use of them. At the same time, through the depiction of historical figures and events in their poetry, they conveyed feelings of love and patriotism for their homeland;

- B.Genjemuratov's intimate lyrics are distinguished by their artistry, the lyrical hero's sensitivity, and the skillful use of artistic devices in character creation. In particular, artistic lines expressing the inner feelings of the lyrical hero inevitably affect the reader's inner world. The poet's intimate poems are not just empty words like «I burned, I loved». It illuminates the lyrical hero's inner turmoil and pure love with unique colors, stirring the reader's emotions. This testifies to the poet's originality and eloquence;

- we have witnessed the frequent use of artistic devices and techniques in the poet's lyrics. In B.Genjemuratov's poetry, artistic imagery serves as the foundation and «soul» of the poem, artistically deepening its meaning and conveying it to the reader's aesthetic sensibilities. This, of course, testifies to the poet's eloquence;

<b>Impact Factor:</b>	<b>ISRA (India) = 6.317</b>	<b>SIS (USA) = 0.912</b>	<b>ICV (Poland) = 6.630</b>
	<b>ISI (Dubai, UAE) = 1.582</b>	<b>ПИИЦ (Russia) = 0.191</b>	<b>PIF (India) = 1.940</b>
	<b>GIF (Australia) = 0.564</b>	<b>ESJI (KZ) = 8.100</b>	<b>IBI (India) = 4.260</b>
	<b>JIF = 1.500</b>	<b>SJIF (Morocco) = 6.004</b>	<b>OAJI (USA) = 0.350</b>

In general, B.Genjemuratov holds a special place in Karakalpak literature. Because they have their own unique voice, unique style, and their own admirers.

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GIF (Australia)	= 0.564	ESJI (KZ)	= 8.100	IBI (India)	= 4.260
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## ICONOGRAPHIC SOURCES AND THEIR ROLE IN THE STUDY OF LEATHER MATERIALS

**Abstract:** This study explores the role of iconographic sources in the investigation of materials used in Georgian ethnographic leather products. Manuscript miniatures and visual representations are analyzed as indirect sources of information on the form, function, and structural characteristics of leather items within historical costume systems.

The research combines iconographic interpretation with material-oriented analysis, focusing on the depiction of clothing, footwear, and decorative elements across different historical periods. The findings demonstrate that, despite their stylized nature, visual sources provide valuable insights into the technological and cultural aspects of leather processing and usage.

The study highlights the importance of integrating art-historical and material-science approaches in order to reconstruct traditional leather products and better understand their evolution within Georgian material culture.

**Key words:** Georgian leather crafts; ethnographic materials; analysis of iconographic materials; leather properties; historical footwear.

**Language:** English

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**Scopus ASCC:** 3316.

### Introduction

Information about leather processing, product construction, and manufacturing technology in Georgia is scarce in written sources about Georgian ethnographic life. The tradition of leather processing and shoemaking is very interesting because it

combines traditions, technology, and cultural symbolism from different ethnographic areas.

Georgian written monuments, including manuscript books and miniatures, represent an important iconographic source that enables the study not only of artistic traditions but also of components

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OAJI (USA) = 0.350

of material culture, such as clothing, accessories, and particularly leather products. In Georgian manuscripts, ornamentation and miniatures occupy a significant place, with the earliest surviving examples dating back to the 9th century.

One of the earliest known examples is the *Anbandidi Gospel*, which belongs to the group of rare manuscripts containing the Four Gospels. Although its initial part has not survived, the preserved fragments still allow for the evaluation of its artistic style, aesthetic principles, and system of decorative elements. Such sources are particularly valuable, as the depicted details provide indirect evidence about the materials used, including leather, as well as their processing techniques and visual characteristics.

During the so-called “Golden Age” of the Georgian state (11th–13th centuries), manuscript decoration reached a high level of development. In the miniatures of this period, including those preserved in the National Archives, both architectural elements and decorative motifs—such as mythical animals, ornaments, and stylized forms—are clearly represented. These compositions not only fulfill an aesthetic function but also indirectly reflect elements of material culture, including structural features of clothing and footwear.

Particularly noteworthy are the miniatures dating from the 13th–14th centuries, where the human figure and costume are depicted in greater detail. For example, in the representation of Saint Shio

Mghvimeli and Evagre, attention is drawn to the form, silhouette, and material perception of secular clothing. This is of considerable importance for historical costume studies and material analysis [1].

From the 14th century onwards, manuscript illumination becomes increasingly detailed. Greater attention is given to background, furniture, and environmental elements. Changes in color palette, taste, and stylistic approaches indicate broader technological and cultural transformations. Art historians identify a so-called “folk stream” in the painting of the 15th–16th centuries, characterized by increased realism and attention to everyday details, including clothing and accessories.

A notable example is the 1494 donation charter to the Bodorna Monastery, commissioned by Eristavi Vamiq Shaburisdze and his consort Dulardukht. The accompanying illustrations, executed in vivid colors, provide valuable information about the clothing of Georgian nobility, textile textures, and ornamental systems. The structural elements of garments presented in these images indirectly indicate the functional and decorative role of materials, including leather.

In the 19th century, newly established styles of manuscript decoration and church painting in Georgia continued to emphasize national motifs. The illustrated publication by Gobron (Mikheil) Sabinin represents an important visual source combining both religious and secular themes [1] (Fig. 1, 2, 3).



Fig. 1. Warrior Saints (St. George, St. Demetre and St. Theodore) and Holy church Fathers (St. Gregory the Theologian, St. John Chrysostom and St. Basil the Great) Gulani, 16th century paper; nuskhuri [1].

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<b>JIF</b>	<b>= 1.500</b>	<b>SJIF (Morocco)</b>	<b>= 6.004</b>	<b>OAJI (USA)</b>	<b>= 0.350</b>



**Fig. 2. Miracle of Liberation by the Princess Versified Life of St. George, 17th century Paper; Mkhedruli [1].**



**Fig. 3. 1795. Donation and marking boundaries charter of King Solomon to Motsameta Monastery paper, mkhedruli Scribe: Presbyter Nikolaos Gabaoni [1].**

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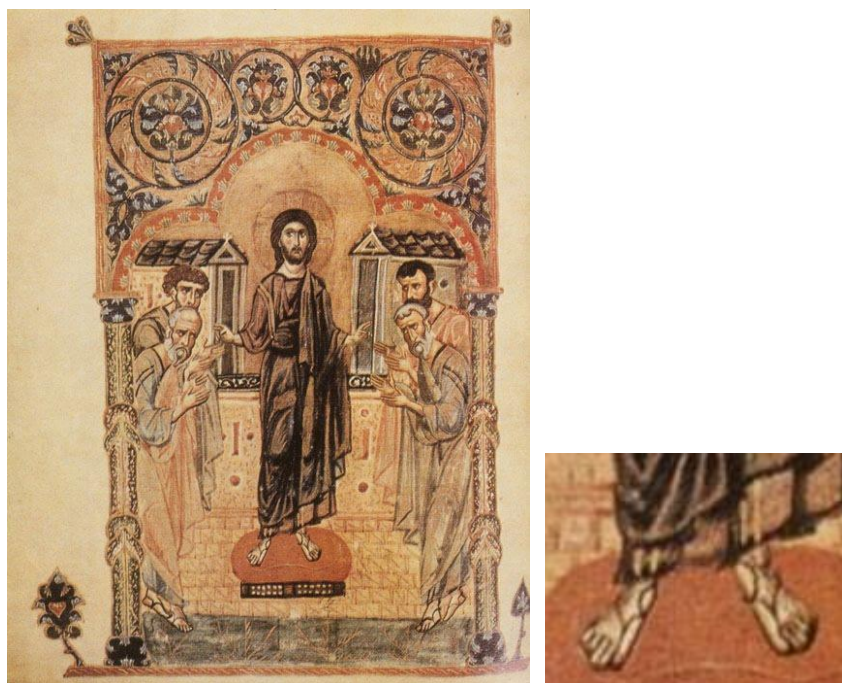


Fig. 4. Vani Four-Headed Tribe, XII-XIII centuries.<sup>1</sup>

It is noteworthy that in iconographic sources, saints, laypeople, and other individuals are often depicted barefoot or wearing simple sandals (Fig. 4).

Although these iconographic sources do not provide direct material-science data, their systematic analysis allows for the reconstruction of the form, function, and usage context of historical leather products. Therefore, they play a crucial role in the study of the evolution of Georgian leather craftsmanship and serve as a foundation for both costume and biomechanical analysis.

This study employs an interdisciplinary methodological framework that integrates iconographic analysis with material-oriented investigation in order to reconstruct the properties, functions, and evolution of leather products within Georgian ethnographic culture. The research is based on a hybrid (QM) model combining qualitative interpretation and empirical observation. The approach bridges art-historical analysis with material science and biomechanics, allowing for a multi-layered understanding of leather artifacts, even when direct physical samples are limited or degraded [2-10].

The methodology relies on three complementary data sources:

- **Iconographic sources** (manuscript miniatures, murals, illustrated documents);
- **Museum artifacts** (preserved leather objects);
- **Field materials** (ethnographic samples obtained from local populations).

Iconographic sources are treated as indirect but highly informative evidence for reconstructing historical leather products.

The integration of iconographic and material analysis provides a novel framework for studying historical leather products. It enables:

- reconstruction of lost or degraded artifacts;
- understanding of material behavior over time;
- connection between cultural representation and physical function.

This approach contributes not only to ethnographic and historical studies but also to modern applications in design, conservation, and material engineering.

Given that this material remains largely unexplored, its systematization and presentation in both album and scientific formats are essential for advancing research on Georgian material culture, particularly leather products. Our team is working on this, and at the final stage of the research, the results of both the study of written sources and the analysis of iconographic material will be presented.

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<sup>1</sup> <https://www.nplg.gov.ge/wikidict/index.php/>.

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## ASSESSMENT OF LOADED STATE OF THE JOURNAL BEARING DURING CHANGES IN THE ROTATION SPEED OF THE JOURNAL

**Abstract:** This article presents the results of calculating the distribution of lubricant pressure in a journal bearing at various journal rotation speeds. The change in calculated pressure in each quarter of the journal bearing circumference is graphically demonstrated. The loaded condition of the journal bearing was determined by its length.

**Key words:** journal bearing, rotation speed, pressure, length.

**Language:** English

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Scopus ASCC: 2206.

### 1. Introduction

The loaded condition of a journal bearing can be evaluated by analyzing parameters such as the thickness of oil film, the distribution of pressure, and the temperature of the bearing, which affect its bearing capacity and stability. When the journal speed is changed, the hydrodynamic lubrication mode changes, which affects the bearing capacity and can lead to increased wear or failure if the bearing is not properly controlled. Methods such as vibration analysis, oil film pressure measurement, and temperature control are commonly used to assess the performance of the bearing and identify any deviations during speed changes, ensuring optimal operation and preventing damage.

The review of scientific papers presented below collectively explores the pressure dynamics in plain bearings using experimental, analytical, and numerical approaches. For example, Gorunov et al. [1] and Aher et al. [5] compare the pressure fields in multi-blade and sliding bearings, noting the impact of blade geometry on bearing capacity. Erhunmwun [2] and Erhunmwun and Akpobi [3] analyze pressure changes using a two-dimensional Reynolds model, taking into account the effects of side leakage, which are critical for high-speed applications. Meili et al. [4] and Panday et al. [8] study the dependence of oil film pressure on time under dynamic loads, revealing hysteresis effects in pressure cycles. Jacobson and Hamrock [10] visualize cavitation using high-speed photography, while Mathieu et al. [9] model three-dimensional turbulent pressure patterns in hybrid bearings. Constantinescu and Galetuse [6] quantify the pressure drop caused by inertia, while Zheng and Hasebe [7] calculate the dynamic coefficients using free-boundary theory. These studies highlight the trade-off between bearing design (blade geometry, notches), operating conditions (speed, load), and fluid behavior (cavitation, turbulence) in optimizing pressure distribution.

The purpose of this study is to determine the loaded state of a journal bearing under various operating conditions using finite element modeling. The practical value of the research is the graphical representation of functions of the lubricant pressure change in the journal bearing in all quarters of the bearing circumference.

### 2. Materials and methods

The calculation of the lubricant pressure distribution in the journal bearing was implemented using finite element modeling. The radius of the rotating shaft model, which is located inside the bearing liner model, and the length of the bearing liner model's contact surface along the shaft model's axis were assumed to be 30 mm and 50 mm, respectively. The clearance between the bearing and journal models

was 0.03 mm. The rotational speed of the journal model varied between 50 and 2000 rpm. The properties of lubricant in the solid-cast journal bearing were added to the calculation domain, taking into account the Reynolds equation for a fluid with a reference pressure of 1 atm, under the condition of no slip of lubricant with a dynamic viscosity of 0.01 Pa·s and a density of 860 kg/m<sup>3</sup>. The densest level of automatic finite element geometry partitioning allowed for the most accurate calculation of the lubricant pressure distribution in the model of the journal bearing.

### 3. Results and discussion

The simulation results are presented in the form of graphs showing the distribution of lubricant pressure in the journal bearing as a function of the journal bearing length at a maximum selected journal rotation speed of 2000 rpm. Changes in pressure were examined at the first, second, third, and fourth quarters of the bearing circumference.

The X-axis on the graphs represents the bearing length in meters.

In graph A, the pressure varies from -10 to 10 Pa. The graph shows the pressure distribution with sharp peaks and valleys near the ends of the bearing length. In the middle part, the pressure is relatively constant and close to zero, with some minor fluctuations. Sudden changes at the boundaries indicate edge effects or the influence of specific operating conditions in that area.

In graph B, the pressure is scaled to 10<sup>6</sup> Pa, ranging from -2 to -0.2. This graph has a parabolic shape, with the maximum pressure occurring at approximately half the length of the bearing. The pressure is negative, indicating a low-pressure area. The pressure decreases towards the edges, reaching its minimum value at the ends.

In graph C, the pressure varies from -0.15 to 0.2 Pa. Similar to graph A, this graph shows sharp oscillatory features near the boundaries (at 0 and 0.05 m). The pressure in the central region is positive and relatively constant, fluctuating around 0.05 Pa. The peaks on the boundaries are more pronounced than on graph A, reaching 0.2 Pa and dropping to -0.15 Pa.

Graph D also has a parabolic shape, similar to graph B, but with positive pressure values.

The graphs illustrate how the pressure distribution inside a plain bearing can vary significantly depending on the specific segment (quarter) of the bearing being analyzed. Graphs A and C probably represent areas where the pressure is unevenly distributed, possibly due to specific geometric features or flow disturbances. Sharp peaks indicate localized areas of high or low pressures.

Graphs B and D show a more typical hydrodynamic pressure distribution within a liquid

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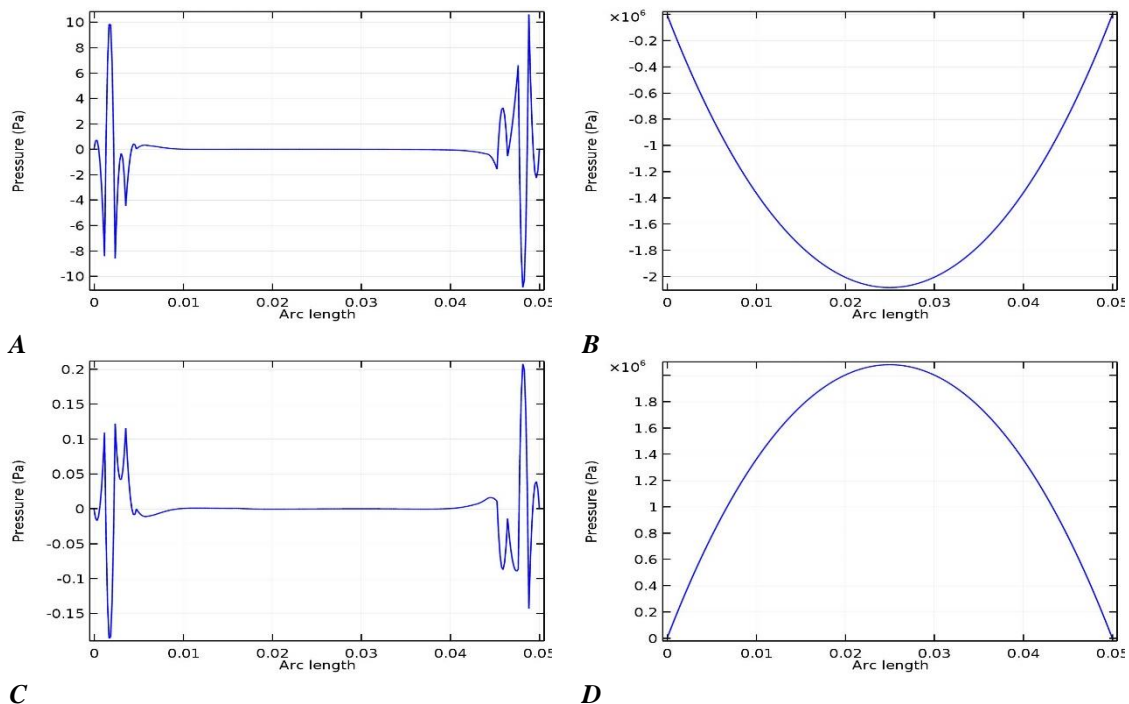
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film. Graph *D* shows a positive pressure profile, indicating the load-bearing capacity in this area. Graph *B* shows a negative pressure profile, which can occur in areas where the liquid film is separating or under stress.

The mathematical description of these pressure distributions usually involves solving the Reynolds equation for thin-film lubrication, taking into account the bearing geometry, fluid properties, and rotational speed. The specific shapes of the curves on each graph are a result of these physical principles and the chosen parameters.

The dependencies of the lubricant pressure distribution in the journal bearing on the length of the journal bearing at other journal rotational speeds changes according to similar functions with an increase in the calculated pressure value. At a speed of journal rotation of 50 rpm, the pressure of lubricant in the journal bearing varies from  $-0.00473$  to  $\pm 52592.25$  Pa; at a speed of journal rotation of 200 rpm, the pressure varies from  $-0.01893$  to  $\pm 210369$  Pa; at a speed of journal rotation of 500 rpm, the pressure varies from  $-0.04733$  to  $\pm 525922.5$  Pa; at a speed of journal rotation of 1000 rpm, the pressure varies in the range from  $-0.09465$  to  $\pm 1051845$  Pa.



**Figure 1. Dependencies of the distribution of lubricant pressure in the journal bearing on the length of the journal bearing at a journal rotation speed of 2000 rpm: A – first quarter, B – second quarter, C – third quarter, and D – fourth quarter.**

## 4. Conclusion

Based on the research results, the following conclusions can be drawn:

1. The lubricant pressure distribution mechanism in the journal bearing was determined along the circumference of the element. In the first and third quarters of the bearing circumference, there is a slight asymmetric distribution of pressure, with maximum pressure at the ends of the bearing and no pressure along the rest of the bearing length. An asymmetric distribution of pressure was also observed in the second and third quarters. At the same time, the pressure value increases many times from the ends of the bearing to the peak value at  $\frac{1}{2}$  the length of the bearing.

2. The lubricant pressure in the journal bearing varies in a wide range from  $0.00473$  to  $\pm 2103690$  Pa at a journal rotation speed of 50-2000 rpm, indicating the dynamic operation of lubricant. Low bearing pressure at low speeds means that the lubricant is not distributed well, and the load is transferred mainly through metal contact. As the journal speed increases, the pressure increases, forming a hydrodynamic lubricant film that reduces friction and wear. This wide range of pressures indicates the complex nature of the bearing's operation, where the lubrication modes change from oil friction to hydrodynamic at different rotational speeds.

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## THE DEGREE OF ACCUMULATED IRREVERSIBLE STRAIN OF METAL ALLOYS WITH TRANSVERSE ANISOTROPY PROPERTIES UNDER CONDITIONS OF DRAWING THIN-WALLED SQUARE PARTS

**Abstract:** This article presents the calculated values for effective plastic strain of certain metal materials with transverse anisotropy properties when drawing thin-walled square-shaped parts. Based on the analysis of the research results, S355MC high-strength low-alloy steel exhibits the greatest accumulated irreversible strain (53.15%), while AISI 304 austenitic stainless steel exhibits the least (22.19%).

**Key words:** drawing, effective plastic strain, drawing depth, transverse anisotropy, blank.

**Language:** English

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### 1. Introduction

Drawing of thin-walled metal sheets is associated with a number of common problems. Folding, characterized by deformation in the flange area due to compressive forces, is a common phenomenon, especially in less rigid thin materials. Tearing or breaking can occur in areas of excessive stretching, such as the bottom or corners, due to the limited tensile strength of the material; thin sheets are particularly vulnerable to localized stress concentrations. The elastic recovery of the material after forming can be more pronounced in thin parts and requires careful compensation to ensure accurate dimensions. Thinning (decreased wall thickness during drawing) and ear formation (wavy edges formed on top) are also problems related to material stretching and anisotropy. Effective lubrication is crucial for minimizing friction, preventing wear, and avoiding surface tears and damage, while maintaining a uniform film is a top priority for thin sheets. Finally, residual stresses may occur, affecting dimensional stability and fatigue life, which requires process optimization or heat treatment. Solving these problems requires careful process design, precise parameter control, optimized tools, appropriate lubrication, and a deep understanding of material properties.

Anisotropy refers to the directional dependence of material properties, which significantly affects behavior during flow, formability, and fracture mechanisms. The Lankford coefficient ( $r$ -value) measures the planar anisotropy of sheet metal, showing how the thickness changes relative to the width under tensile stress. This is the ratio of true width strain to true thickness strain. A value of  $r$  equal to 1 indicates isotropic behavior. Values of  $r > 1$  are favorable for deep drawing, minimizing thinning. Values of  $r < 1$  indicate greater thinning than in the case of isotropic drawing. The articles collected below provide valuable information about the complex behavior of anisotropic materials, especially metals such as aluminum and steel, during plastic deformation and the forming of sheet metal.

Key research, such as the work of Bron and Besson [1], develops yield functions tailored to anisotropic materials, allowing for more accurate predictions of metal deformation. Banabic et al. [2, 3] investigate the relationship between anisotropy and formability, highlighting advances in modeling and experimental methods. Other works, such as those by Ma et al. [4], investigate the role of sheet thickness stresses that affect the limits of forming. Deep drawing is considered from the perspective of stability

and failure, with researchers such as Ruzanov [5] and Nikolov et al. [6] focusing on process optimization and experimental verification. The article by Voronin and Ushin [7] explores how the anisotropy of the AD1M alloy affects the geometry of hollow cylindrical parts during drawing. Meanwhile, research on the evolution of fracture and plastic damage (Khelifa et al. [8], Volk et al. [9]) contributes to improving the prediction of fracture under complex deformation paths. Kuwabara, Van Bael, and Iizuka [10] investigate the measurement and analysis of the yield curve and strain hardening characteristics in steel sheets, emphasizing the influence of different values of  $r$ . Finally, Wang and Sun [11] present an analysis of the transverse anisotropy of plane deformation for modeling the forming of sheet metal using the 6-component Barlat yield function.

Based on the a priori analysis of the problematic issues in implementing the process of drawing metal sheets into thin-walled products under production conditions, the following objectives of this study were formulated:

1. Perform finite element modeling of the drawing process for thin-walled square-shaped products made of various materials to compare the deformed state of a part with a specific geometry.
2. Estimate the effect of mechanical properties and the Lankford coefficient on the degree of effective plastic strain of the material.
3. Provide recommendations on the stability of each material under study during the drawing process.

### 2. Materials and methods

The analysis of accumulated irreversible strain during the drawing of thin-walled square-shaped parts was performed for the following metal alloys: DC05 high-quality cold-rolled low-carbon steel, DC01 structural high-quality carbon steel, S355MC high-strength low-alloy steel, AISI 304 austenitic stainless steel, 5754 deformable aluminum alloy, and Ti Grade 4 commercially pure titanium. Each selected material exhibits transverse anisotropy properties, which is critical for accurate modeling of stamping and drawing processes. The properties of materials subjected to plastic deformation are presented in Table 1.

The calculation of effective plastic strain was performed using the LS-DYNA program, which was used to create models of 200×200 mm square sheet blanks with a thickness of 0.8 mm, a 145×145 mm square punch, a blankholder, and a die with a square hole, as well as to set the conditions for finite element modeling of the process. The gap between the surfaces

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of the punch and the die hole is 2.5 mm. The surfaces of the punch and the die hole had radii of 40 mm to reduce local stresses in the blank material. The sheet

blank was drawn to a depth of 20 mm by moving the punch model along the Z-axis at a constant speed.

**Table 1. Properties of materials that can be drawn.**

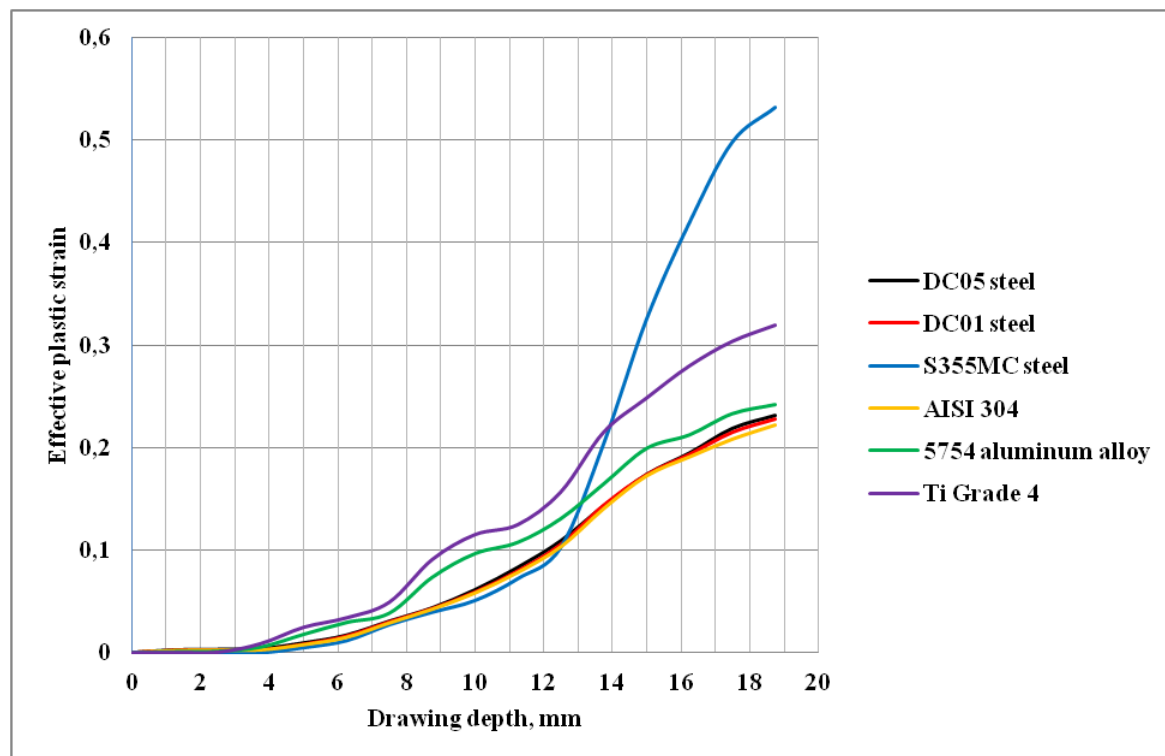
Property	DC05	DC01	S355MC	AISI 304	5754	Ti Grade 4
Density, g/cm <sup>3</sup>	7.87	7.85	7.85	7.93	2.66	4.51
Young's modulus, GPa	210.0	210.0	210.0	196.0	70.0	105.0
Poisson's ratio	0.3	0.3	0.3	0.29	0.33	0.36
Initial yield strength, MPa	160.0	196.0	355.0	210.0	80.0	500.0
Tangent modulus, GPa	2.1	2.1	2.1	2.1	0.8	1.5
Lankford coefficient	2.0	1.4	1.0	1.0	0.7	4.0

The choice of a square section of the blank in this study is based on its geometric features, material behavior, and tool design, which require a thorough analysis of the material's stress-strain state at all stages of the manufacturing process. Round profiles provide uniform stress distribution, predictable material flow, and a simpler design for forming tools, resulting in high production efficiency and reduced equipment wear. While square profiles are characterized by sharp angles and complex geometry, which lead to stress concentration, difficulties in material flow, and the need for more durable and complex tools, these factors

also increase the risk of defects and reduce productivity [12-13].

### 3. Results and discussion

The graph in Figure 1 shows the dependence of drawing depth along the X-axis on the effective plastic strain along the Y-axis. Six different curves were obtained, each representing a separate material under study. The curves illustrate the accumulation of effective plastic strain for each material as the drawing depth increases.



**Figure 1. Dependence of the effective plastic strain of materials on the drawing depth.**

All materials exhibit minimal plastic strain at the beginning of the drawing process. The curves are almost horizontal and close to zero.

S355MC high-strength low-alloy steel demonstrates a significantly higher rate of plastic

strain accumulation at greater drawing depths compared to other steels. The material curve increases dramatically at a depth of 12 mm.

Ti Grade 4 commercially pure titanium also demonstrates a significant increase in plastic strain

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with greater drawing depth, but its growth begins slightly earlier and is less pronounced compared to S355MC high-strength low-alloy steel.

5754 deformable aluminum alloy is characterized by a moderate increase in plastic strain with increasing drawing depth (lower than S355MC steel and Ti Grade 4), but generally higher than other steels at greater drawing depths.

DC05 high-quality cold-rolled low-carbon steel, DC01 structural high-quality carbon steel, and AISI 304 austenitic stainless steel have a more stable and relatively lower accumulation of plastic strain compared to the other materials studied, especially at a drawing depth of more than 12 mm. In this range, their curves tend to be closer together.

A material with a curve that rises more slowly and achieves greater plastic strain before failure (if failure were obvious) is generally considered more formable. Conversely, a material that exhibits a rapid increase in strain and potentially reaches its limit may be less formable or more prone to failure.

Materials with higher yield strength and Young's modulus (such as S355MC high-strength low-alloy steel) tend to resist initial deformation better, but they can experience significant plastic strain at higher drawing depths.

The higher Lankford coefficient (for example, for Ti Grade 4 commercially pure titanium) typically results in better formability in drawing processes, which means that the material can be stretched into complex shapes without excessive thinning or tearing. The dependence for Ti Grade 4 commercially pure

titanium shows a significant increase in plastic strain, but the high Lankford coefficient indicates that this strain can be controlled.

Understanding these curves can help engineers choose the right material for a specific application and optimize the drawing process to avoid defects such as breakage or excessive thinning.

## 4. Conclusion

During the drawing process, the sheet material is stretched, compressed, and bent. The degree of strain of a metal alloy during plastic deformation can be represented by the effective plastic strain coefficient. Based on the results of the study, it can be concluded that the accumulated irreversible strain is almost the same for DC05 and DC01 steels during shallow drawing and does not exceed 0.23 (23%), indicating a stable process of product formation without significant thinning of the walls or cracking of the material. However, with an increase in the initial yield strength and a decrease in the Lankford coefficient (S355MC high-strength low-alloy steel), the drawing process occurs with significant plastic deformation (the effective plastic strain coefficient reaches 0.5315 or 53.15%), which potentially leads to material defects. Therefore, S355MC high-strength low-alloy steel and Ti Grade 4 commercially pure titanium must be drawn with caution, as the hardness of these deformable materials increases and the ductility decreases. The most suitable material for the drawing process is AISI 304 austenitic stainless steel.

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## MOISTURE AND SALT TRANSPORT DURING THE ECOLOGICAL RESTORATION OF HEAVILY SALINATED SOILS

**Abstract:** *In the context of ecological rehabilitation of heavily salinated soils, the rate of moisture and salt movement through the soil is of particular significance. This rate is contingent on the soil's composition and is subject to variation in accordance with the irrigation methods and technologies employed. Formulas have been developed to determine the relationship between water evaporation from the soil surface and the movement of groundwater. The rate of evaporation is influenced by a number of factors, including soil type, the depth of the water table, and the chemical composition of the salt. Formulas have been derived to determine the relationship between air exchange, moisture exchange and nutrient exchange in the soil. The research conducted examined solutions to the problems of salinisation and heat release in the soil.*

**Key words:** *Geo-ecosystem, geo-ecology, heat exchange, mathematical model, soil-water system, salt exchange in soil, soil filtration, soil-plant system, moisture exchange, ecological-mathematical model.*

**Language:** English

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### Introduction

The movement of moisture within the soil is contingent upon the water absorption capacity and mechanical composition of the soil under investigation. The transport of moisture from the genetic soil layer is subject to variation due to the

volume of water supplied, the laws of gravitational and spontaneous movement, the methods and technologies employed for water supply, as well as the structure and distribution of the soil and vegetation cover.

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The movement of moisture through the soil is contingent on the depth of the groundwater table and the nature of the groundwater itself. The movement of moisture in the soil is driven by the forces of capillarity, which cause it to rise and fall through the soil's tubular structure and along its inclines. In the event of a decline in moisture movement, resulting in stagnation, the accumulated moisture and water reserves gradually ascend due to the phenomenon of capillary action. Such phenomena, particularly in the context of soil formation processes, are more commonly observed in areas where the groundwater table is shallow (2–3 cm). At this level, the rising water forms a concentration of mineral salts. In the coarse-textured, low-moisture soil layer, the remaining plant roots are damaged, and transpiration along the roots increases. It is evident that the soil composition is subject to two primary factors. Firstly, the process of evaporation causes moisture to be drawn from the soil layers by dry air. Secondly, waterlogging of the plant roots results in a reduction in their productivity [1].

At a given point in time ( $\tau$ ), the rate of moisture rise ( $V$ ) along the capillary is equal to

$$V_{\tau} = (dh/d\tau)\tau = k \frac{P - h\tau}{h\tau}, \quad (1)$$

If we integrate this equation:

$$\tau = \frac{1}{k} \left[ h\tau + p \ln \left( \frac{P - h\tau}{p} \right) \right]. \quad (2)$$

The rate of water absorption during the initial stage of the rise in water level can be determined using a very simple equation:

$$h < P \text{ when } (dh/d\tau)\tau = KP/h\tau \quad (3)$$

After integration, we obtain:

$$\tau = h^2 / 2KP, \quad (4)$$

In a laboratory setting, we can verify the close relationship between theoretical and experimental data by placing sandy soils in columns. If we consider the equation for this calculation, taking into account the period of the final rise in water level, the equation can be written as follows:

$$\tau = -\frac{1}{k} [h\tau - P \ln P + P \ln(P - h\tau)], \quad (5)$$

The force driving the movement of water is equal to the sum of two quantities: the difference between the capillary pressure ( $P_v$ ) and the lower pressure, and

the height of the water level in the capillary at time  $\tau(h\varepsilon)$ .

Accordingly, the velocity of the water:

$$\left( \frac{dh}{d\tau} \right)_{\tau} = K \frac{P_{bl} - P_R + h\varepsilon}{h\varepsilon} = K \frac{\Delta P + h\varepsilon}{h\varepsilon}, \quad (6)$$

If we separate and integrate the rotations:

$$\tau = -\frac{1}{K} \left( h_0 - h\tau - \Delta P \ln \frac{h_0 + \Delta P}{h\varepsilon + \Delta P} \right), \quad (7)$$

As the analysis of this equation shows, the rate of water transport increases as the amount of residual water decreases, where  $P_{bl}$  is a constant.

Changes in soil moisture depend on the level and thickness of the genetic layer, its hydraulic conductivity, and the upper and hygroscopic moisture capacities [2]. The intensity of evaporation from the soil surface is determined by solar radiation, temperature, air humidity, wind speed and soil surface moisture content.

The permeability of soil and the amount of heat it contains make it possible to determine the role of evaporation processes, as well as the upward and downward movement of soil layers. This allows us to understand the condition of living organisms in the layer where plant roots extend and their impact on the environment. It also enables us to assess the ecological effects of human activities on agricultural production.

General methods for determining the infiltration process are known. The most well-known of these is the Fymer method, in which, using the basic equation of motion and the following expression, known as the

“Boltzmann transformation” ( $\varphi = x\tau^{-\frac{1}{2}}$ , where  $x$  is the distance along the flow path and  $\tau$  - is time), the solution for the depth of moisture penetration ( $z$ ) is obtained in the form of a power series:

$$Z = \varphi\tau^{1/2} + x\tau + \psi\tau^{3/2} + \dots + F_b\tau^{n/2}, \quad (8)$$

where the coefficients  $\varphi, x, \psi, \dots, F_n$  are functions of soil moisture ( $W$ ) that can be solved numerically using a system of ordinary differential equations.

From the physical properties of soil and the case of a homogeneous formation, it is known that, depending on its moisture content:  $kc = const, \Delta P = const$  and  $\Delta W = const$ .

$$\tau = \int_0^h \frac{\Delta W h \varepsilon dh}{K(\Delta P + h\varepsilon)}, \quad (9)$$

After integrating this expression:

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$$\tau = \frac{\Delta W}{K} \left[ h_{\tau} - \Delta P \ln \left( 1 + \frac{h_{\tau}}{\Delta P} \right) \right], \quad (10)$$

Equation (10) can be used to solve many critical problems in sustainable agriculture, such as determining how long it takes to moisten the soil to a specific depth and how much water the soil absorbs, or determining the depth of moisture penetration and how much water is absorbed at a specific point in time.

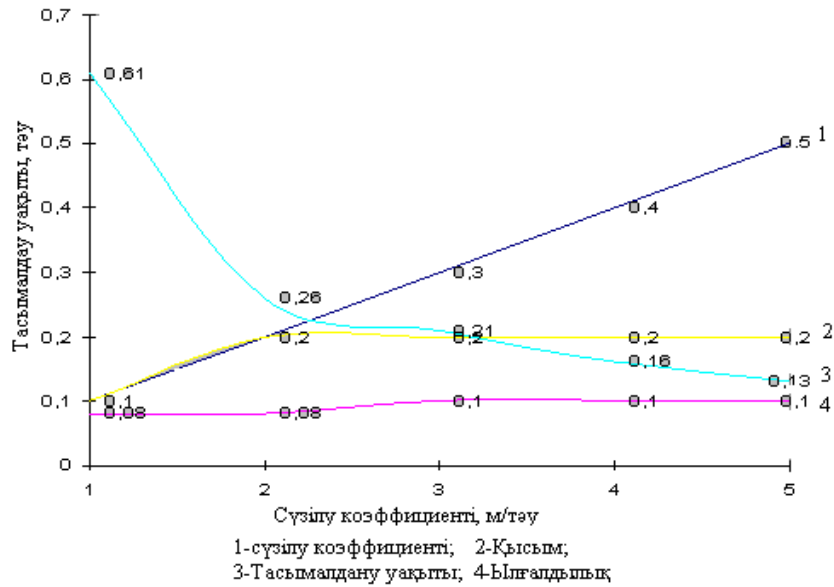
According to this expression (10), data were collected using the monolithic method ((x)m²) and (2×2,m²) in which a tree located at a depth of 30–50 cm was surrounded on all four sides and watered from a bucket (5–6 hours), and observations were conducted over 12–16 hours depending on soil permeability. The experimental data corresponded to

changes in soil infiltration rate and pressure in the soil layers. In such cases, observations were required for 3 to 77 hours. (Tables 4–5).

In studying the ecological formation of grey soils within the geosystem using laboratory and field monoliths, and taking into account data on various soil groups based on mechanical composition, filtration coefficients, moisture content and soil layer porosity, we observed the results presented in Tables 1–2 and Figures 1–2. From an ecological standpoint, the more compact the soil, the lower its filtration capacity and the longer the moisture transfer time (1.03–3.2 days). Conversely, a high filtration capacity (0.1–0.5 m/day) results in a shorter moisture transfer period (0.61–0.13 days). These principles enable the accurate and rapid determination of the moisture transfer time in both saturated and unsaturated soil conditions, as well as in a compacted soil crust.

**Table 1. Water transfer by filtration and pressure**

$K_S$ filtration coefficient, m/day	Moisture absorbed into the soil W, m	Soil layer $h_{\tau}$ , m	Atmospheric pressure $\Delta P$ , atm	Period of increased humidity $\tau$ , day
0,1	0,08	1	0,1	0,61
0,2	0,08	1	0,2	0,26
0,3	0,1	1	0,2	0,21
0,4	0,1	1	0,2	0,16
0,5	0,1	1	0,2	0,13



**Figure 1. Water transport as a function of filtration and sedimentation.**

**Table 2. Water flow rates as a function of filtration and pressure.**

$K_S$ , m/day	W, m	$h_{\tau}$ , m	$\Delta P$ , atm	$\tau$ , day
0,05	0,08	1	0,20	1,03
0,04	0,08	1	0,2	1,28
0,03	0,1	1	0,2	2,13
0,025	0,1	1	0,2	2,56

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0,020	0,1	1	0,2	3,2
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In conclusion, the rate at which soil is transported and moves depends directly on its mechanical composition. Additionally, fluctuations in

wastewater levels depend on the pipes in the soil layer, as well as on irrigation methods and technologies.

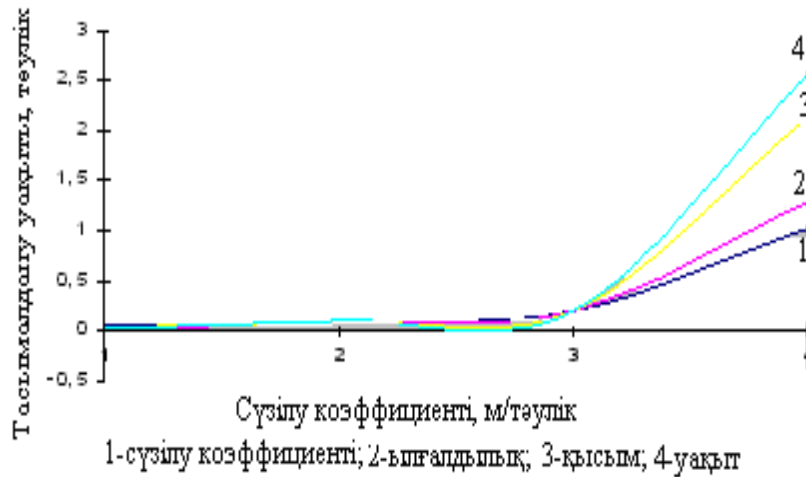


Figure 2. Water transport as a function of filtration and sedimentation.

Let's examine the relationship between groundwater evaporation and the transfer of heat and moisture in geocosystems.

In order to produce a crop naturally, the soil, water, plants and necessary heat, air and nutrients must be present. Thoroughly studying the structure and interrelationships of these components in the natural environment enables us to understand how modern ecosystems and landscapes form, and how society and its natural environment can be properly stabilised.

While fertilisers and other nutrients are supplied to the soil layer for distribution, tillage and water infiltration, on the other hand, it becomes degraded, water scarcity arises and yields decline. To prevent such adverse environmental impacts, it is necessary to systematically analyse each genetic layer of the land in use, including its moisture reserves, the corresponding heat, and the insufficiently studied evaporation processes at the soil surface and in the groundwater zone. This requires the identification of specific solutions to address these issues.

The following expressions describe the physical, mathematical and ecological implications of the relationship between soil depth, plants and groundwater.

The shape of the water entering the root canals is that of a semicircle. In this case, the volume of water passing through this semicircle is equal to [3]:

$$Q_1 = -2\pi l^2 \rho_{\text{ж}} K \frac{dW}{dl}, \quad (11)$$

where  $-2\pi l^2$  is the surface area of the semishell;  $Q_1$  is the volume of water entering the root canals;  $K$  is the average efficiency coefficient;  $\rho_{\text{ж}}$  is the density of water.

After integrating this expression:

$$Q_1 = -2\pi l \rho_{\text{ж}} K \frac{1}{\frac{1}{l_0} - \frac{1}{l}} (W - W_k), \quad (12)$$

where  $W_k - l=l_0$  represents the soil moisture content, i.e., at the surface of the root channels; then the expression  $l \geq l_0$ , (193) takes the form:

$$Q_1 = -2\pi \rho_{\text{ж}} K l_0 (W_{\infty} - W_R), \quad (13)$$

where  $W_{\infty}$  represents the soil moisture content at a large distance between root tubes;  $l$  represents the radius of the semicircle. The equation for water evaporation from the plant's root tubes (transpiration) and moisture exchange between the leaf's parenchyma cells and its surface is as follows:

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$$E_T = \rho_a \frac{A_m}{\delta_z} (q_0 - q_\delta), \quad (14)$$

where  $E_T$  is evaporation (transpiration),  $g/cm^2 \cdot s$ ;  $\rho_a$  is the density of air;

$A_m$  is the molecular diffusion coefficient;  $\delta_z$  is the distance traveled by a water vapor molecule from the surface of a parenchyma cell to the outer surface of the leaf;  $q_0$  and  $q_\delta$  are the specific humidity of the air at the surface of the parenchyma cell.

The correct equation for moisture exchange between the leaf surface and the air is derived from an analysis of evaporation from the soil surface [4]:

$$E_T = \rho_a \cdot D_0 (q_0 - q_\delta), \quad (15)$$

where  $D_0$  is the mass transfer coefficient between the leaf and the air surface;  $q_0$  and  $q_\delta$  are the specific humidity of the air at the leaf surface and at a height of 2m.

Determining soil structure and the location of the groundwater table within the geo-ecosystem, as well as evaporation from the groundwater surface (EFWS), is of great importance in agricultural research [5]. Formulas can be used to provide the necessary data for a more in-depth study of these phenomena and their underlying mechanisms.

First and foremost, evaporation from the soil surface and the parameters required for it are directly related to humidity in different regions and depend on soil type. For the sandy soils of Central Asia, evaporation from the soil surface is determined by N.N. Ivanov's formula:

$$E_0 = 0.0018 \cdot (25 + t)^2 \cdot (100 - a), \quad (16)$$

where:  $E_0$  – evaporation from the soil surface, mm;  $t$  – air temperature, °C;  $a$  – relative air humidity, %;

The parameters of the soil aeration zone (EFWS) are determined experimentally for various soil groups (I–V) [74]. As shown by long-term studies, the mineral content of groundwater, depending on soil composition, as determined by monolithic experiments, ranged from 3 to 50 g/L. The degree of salinity was 0.25–2%. In this context, the hydrophysical properties of the soil were taken into account based on the following formula [6]:

$$E_{\text{всбб}} = E_0 \cdot \left(1 - \frac{H}{H_{\text{ТСК}}}\right) \cdot e^{-nH} \quad (17)$$

where  $E_{\text{всбб}}$  is groundwater evaporation from the surface,  $m^3/ha$ ;  $H$  — is the groundwater depth, m;  $H_{\text{ТСК}}$  — is the soil's water-holding capacity, m;  $n$  is a parameter accounting for the soil's hydrophysical properties;  $e$  — is the base of the natural logarithm.

The amount of salt can be determined in soil layers formed within a geocosystem based on groundwater depth, mineral composition, and moisture reserves [7]:

$$S_1 = \frac{E_{\text{всбб}} \cdot C}{10^3 \gamma_c}, \quad (18)$$

where:  $S_1$  — salt content, t/ha;  $C$  - mineral content in groundwater, g/L;

$\gamma_c$  — density of water,  $kg/m^3$ .

And the degree of salinity:

$$S_2 = \frac{S \cdot \gamma_T \cdot E_{\text{всбб}}}{10^3}, \quad (19)$$

where:  $S_2$  – salinity index, %;  $\gamma_T$  – soil density,  $t/m^3$ ;  $S_0$  – initial salinity, % (Appendix B)

Based on formulas (16–19), we have outlined the primary conditions required for groundwater evaporation. We established that groundwater evaporation in a geosystem is directly related to the effect of heat on the soil surface during weather changes, as well as to the movement of moisture reserves within the soil layer. Equations (16–19) also show that the amount of water entering the root channels, and the rate at which it is taken up, depend on the thickness of the soil layer, evaporation from the root channels, and the humidity of the air at the leaf surface

Thus, the above formulas (11–20) are closely interrelated. Studies [6–8] have demonstrated that the rate of moisture evaporation from the soil surface corresponds to the moisture content in the EFWS soil layer. Therefore, to achieve high agricultural yields, it is necessary to conduct in-depth, systematic studies of groundwater evaporation in geo-ecosystems and of the transport of moisture through soil and plants, based on underlying principles. Furthermore, evaporation rates in various situations that directly influence this effect depend on soil type, groundwater depth, the chemical composition of salts and the type of vegetation in the natural environment and landscape, as well as the research methods employed.

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Article



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## AN ASYMPTOTIC REPRESENTATION OF THE GENERAL SOLUTION TO A HOMOGENEOUS DIFFERENTIAL SYSTEM WITH VARIABLE COEFFICIENTS CONTAINING A LARGE PARAMETER

**Abstract:** In the context of solving problems in mechanics described by second-order differential equations and systems of differential equations with variable coefficients containing a large parameter, questions arise regarding the calculation of characteristics related to changes in the parameter. Consequently, questions arise regarding the influence of the parameter and its variation on the general solution of the system. The present article considers the determination of the general solution to a homogeneous 2nd-order differential equation system with variable coefficients, containing a large parameter and having multiple roots of the characteristic equation.

**Key words:** parameter, characteristic matrix, asymptotic solution, multiple roots, rank, elementary divisors of a matrix.

**Language:** English

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### Introduction

Mathematical models in mechanics problems are characterized by a high degree of complexity. In the context of linear problems, the presence of a wide range of numerical values for the system's parameters, the high order of the differential equations, the variable coefficients in these equations, and the large number of algebraic equations results in a complex interplay of factors that complicates both analytical investigation and the derivation of a numerical solution. Conversely, in instances where the

constituent elements of the object under scrutiny exhibit substantial variations in their characteristics, the implementation of suitable parameters becomes imperative. This facilitates the execution of an asymptotic analysis of the mathematical model or the numerical method employed in addressing the problem. It is evident that the asymptotic analysis of complex mathematical models of mechanical systems can yield simplified versions of these models. Furthermore, the utilization of numerical methods in subsequent research can be facilitated by this analysis.

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The analysis demonstrates that the asymptotic behavior of the numerical algorithm is highly significant for large integration steps. It is evident from this analysis that novel methodologies for the numerical resolution of problems can be proposed for a range of mechanical problems.

When solving a system of 2<sup>nd</sup>-order differential equations:

$$\begin{cases} \dot{y}_1 + a_{11}y_1 + a_{12}y_2 = 0, \\ \dot{y}_2 + a_{21}y_1 + a_{22}y_2 = 0, \end{cases} \quad (1)$$

with coefficients  $a_{ij}$  expressed in the form:

$$a_{ij}(t, \lambda) = \lambda^p a_{ij}^p(t) + \lambda^{p-1} a_{ij}^{p-1}(t) + \dots + a_{ij}^0(t) + \dots$$

it is assumed that, as the time  $t$  varies within the interval under consideration, the roots of the characteristic equation:

$$\begin{vmatrix} a_{11}^{(p)} + \mu & a_{12}^{(p)} \\ a_{21}^{(p)} & a_{22}^{(p)} + \mu \end{vmatrix} = 0 \quad (2)$$

are distinct and do not tend to zero. This assumption made it possible to apply the method of asymptotic expansions to solutions of differential equations containing a large parameter.[1]

In the event that system (1) is found to possess multiple roots, this fact must be taken into consideration. The investigation will ascertain the manner in which the presence of multiple roots will affect the solution of the system. It is evident that the presence of repeated roots can give rise to the emergence of internal resonances. Consequently, internal resonances will induce a qualitative change in the behaviour of the solutions, signifying that oscillating solutions will begin to manifest periodic changes, the growth characteristics of aperiodic solutions will undergo modification, and so forth.

However, it should be noted that multiple roots do not invariably result in the occurrence of internal resonances. It is conceivable that a system exhibiting multiple frequencies may demonstrate a behaviour analogous to that of a system with non-multiple frequencies. To illustrate this point, consider a spherical pendulum. This system exhibits multiple frequencies yet does not lead to the emergence of secular motions. [2]-[3]

The question of how system (1) behaves in the presence of multiple roots depends on whether the elementary divisors of the matrix  $\|a_{ij}^{(p)}\|$  of the form:

$$\|a_{ij}^{(p)}\| = \begin{vmatrix} \gamma_1 & 1 \\ 0 & \gamma_2 \end{vmatrix}. \quad (3)$$

where  $\gamma_i$  are roots of the characteristic equation (2).[4]

If the multiplicity of the elementary divisor is two, the Jordan form of the matrix of system (1) is given by:

$$\|a_{ij}^{(p)}\| = \begin{vmatrix} \gamma & 1 \\ 0 & \gamma \end{vmatrix}. \quad (4)$$

It should be noted here that in both cases where  $\gamma_1 = \gamma_2 = \gamma$ , the root of the characteristic equation has a multiplicity of two; the behavior of the solutions to system (1) and the asymptotics as  $\lambda \rightarrow \infty$  will be different.

A general analysis of systems in which the characteristic equation may have multiple roots is not only cumbersome but also difficult. It is important to note that the coefficients of the characteristic equation are dependent on the variable of time. This leads to the potential for a multitude of scenarios to emerge.

Let us consider the case of simple elementary divisors. To begin with, suppose that the rank of system (1) is one. Next, suppose that the independent variables are chosen such that the matrix  $\|a_{ij}^{(p)}\|$  is in Jordan form.[4]

Let us consider case (3). Given that the nature of the roots, and thus the form of the Jordan form, depend on time, this approach makes sense only if the situation under consideration remains unchanged throughout the entire time interval under investigation.[1], [5]–[6]

If the roots are multiple but the elementary divisors are prime, then the system of equations (1) can be transformed into the form:

$$\begin{cases} \dot{y}_1 + (\lambda\mu + a_{11}^{(0)} + \dots)y_1 + (a_{12}^{(0)} + \dots)y_2 = 0, \\ \dot{y}_2 + (a_{21}^{(0)} + \dots)y_1 + (\lambda\mu + a_{22}^{(0)} + \dots)y_2 = 0. \end{cases} \quad (5)$$

In system (5), the points denote terms of higher order with respect to  $1/\lambda$ . Let us introduce the following substitution:

$$y_1 = e^{-\lambda \int_0^t \mu(t) dt} z_1, \quad y_2 = e^{-\lambda \int_0^t \mu(t) dt} z_2, \quad (6)$$

according to which the system of equations (5) will contain no first-order terms with respect to  $\lambda$ :

$$\begin{cases} \dot{z}_1 + (a_{11}^{(0)} + \dots)z_1 + (a_{12}^{(0)} + \dots)z_2 = 0, \\ \dot{z}_2 + (a_{21}^{(0)} + \dots)z_1 + (a_{22}^{(0)} + \dots)z_2 = 0. \end{cases} \quad (7)$$

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If the coefficients  $a_{ij}$  did not contain terms of order  $\lambda^{-1}$  or higher, the task of constructing the asymptotic series would be complete. Indeed, in that case, system (3. 7) would take the following form:

$$\left. \begin{aligned} \dot{z}_1 + a_{11}^{(0)} z_1 + a_{12}^{(0)} z_2 &= 0, \\ \dot{z}_2 + a_{21}^{(0)} z_1 + a_{22}^{(0)} z_2 &= 0. \end{aligned} \right\} \quad (8)$$

Let  $z_{1i}$  and  $z_{2i}$  ( $i = 1,2$ ) be the fundamental solutions of system (7). These functions can certainly be obtained by numerically solving two Cauchy problems with the initial conditions:

$$\text{I. } \begin{cases} z_{11}(0) = 0, \\ z_{21}(0) = 1. \end{cases} \quad \text{II. } \begin{cases} z_{12}(0) = 1, \\ z_{22}(0) = 0. \end{cases}$$

Therefore, the asymptotic representations of the general integral of system (5) will be expressed as:

$$\left. \begin{aligned} y_1 &= e^{-\lambda \int_0^t \mu(\epsilon) dt} (C_1 z_{22} + C_2 z_{12}), \\ y_2 &= e^{-\lambda \int_0^t \mu(\epsilon) dt} (C_1 z_{21} + C_2 z_{11}). \end{aligned} \right\} \quad (9)$$

When the coefficients  $a_{ij}$  are expressed as negative powers of the parameter  $\lambda$ , methods from perturbation theory are used to construct the function  $z_i$ . For example, finding the solution to system (6) in the form of a series in powers of  $\lambda^{-1}$ . [1],[6]-[8]

In the case of non-simple elementary divisors, the Jordan normal form takes the form (4). Then system (5) will be written in the following form:

$$\left. \begin{aligned} \dot{y}_1 + \left( \lambda \mu + a_{11}^{(0)} + \dots \right) y_1 + \left( \lambda + a_{12}^{(0)} + \dots \right) y_2 &= 0, \\ \dot{y}_2 + \left( a_{21}^{(0)} + \dots \right) y_1 + \left( \lambda \mu + a_{22}^{(0)} + \dots \right) y_2 &= 0. \end{aligned} \right\} \quad (10)$$

The identification of a solution to system (10) in the form of (6) would signify that the system of equations with respect to  $z_i$  would comprise 1<sup>st</sup>-order terms in the parameter  $\lambda$ . Consequently, solutions of the form (10) are generally deemed to be unfeasible.

The subsequent discussion will concern a practical problem that reflects the theory described above. It is imperative to consider the motion of a body in air, which takes place in the direction of a certain vector,  $z^0$ . It is hypothesised that the body possesses an axis of symmetry, designated as  $\xi^0$ . In the context of the aforementioned motion, an aerodynamic moment is exerted on the body in the plane of the angle of attack, denoted by the symbol  $v$ . The angle of attack is defined as the angle between the vector  $z^0$  and the axis of symmetry of the body. The hypothesis under consideration is that the body does

not rotate about the axis. The motion of the body is described by a homogeneous system of equations:

$$\left. \begin{aligned} \ddot{x} + \lambda^2 \omega^2(t)x + \lambda a y &= 0, \\ \ddot{y} + \lambda^2 \omega^2(t)y + \lambda b x &= 0. \end{aligned} \right\}, \quad (11)$$

which has two degrees of freedom. The generalized coordinates of the system (1) are taken to be the direction cosines of the symmetry axis vector  $\xi^0: x = \cos(\xi^0 x^0)$ ,  $y = \cos(\xi^0 y^0)$ .

It was hypothesised that the body possessed axial symmetry. Consequently, for small angles of attack, a linear formulation was employed. The process described results in the system of equations (1) being reduced to two equations with respect to both generalised coordinates. It can be shown that these equations will be independent.:

$$\left. \begin{aligned} \ddot{x} + \lambda^2 \omega^2(t)x &= 0, \\ \ddot{y} + \lambda^2 \omega^2(t)y &= 0. \end{aligned} \right\} \quad (12)$$

where  $\lambda^2 \omega^2$  represents the ratio of the restoring torque to the equatorial moment of inertia. In reality, the restoring torque is sufficiently large, and consequently the motion is treated as high-frequency. [5]

If we assume a slight asymmetry in the body, then the reference frame for the motion of such a body is system (1). Introducing new notation:

$$x = x_1, \quad y = x_3,$$

the system will be converted into the following form:

$$\left. \begin{aligned} \dot{x}_1 &= \lambda x_2, \dot{x}_2 = -\lambda \omega^2 x_1 - a x_3, \\ \dot{x}_3 &= \lambda x_4, \dot{x}_4 = -\lambda \omega^2 x_3 - a x_1. \end{aligned} \right\} \quad (13)$$

The last system (3) is a generalisation of system (1). Let us prove that system (3) has two roots, each of which has order two. Let us make the following substitution in system (1):

$$\begin{aligned} x &= \xi_1 + \xi_3, & \dot{x} &= i\lambda \omega (\xi_1 - \xi_3), \\ y &= \xi_2 + \xi_4, & \dot{y} &= i\lambda \omega (\xi_2 - \xi_4). \end{aligned}$$

Substituting the above expression into equation (1) will result in the following expression:

$$\left. \begin{aligned} \xi_1 &= i\lambda \omega \xi_1 + \dots, \\ \xi_2 &= i\lambda \omega \xi_2 + \dots, \\ \xi_3 &= -i\lambda \omega \xi_3 + \dots, \\ \xi_4 &= -i\lambda \omega \xi_4 + \dots. \end{aligned} \right\}, \quad (14)$$

where the dots denote terms that do not contain  $\lambda$ . When the characteristic matrix of system (14) is

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reduced to diagonal form, the matrix will take the form:

$$\left\| \begin{array}{cccc} i\omega - \mu & & & \\ & i\omega - \mu & & \\ & & -i\omega - \mu & \\ & & & -i\omega - \mu \end{array} \right\|.$$

As can be clearly seen, system (13) has two roots, each of order two. Furthermore, the elementary divisors of the characteristic matrix are prime.[4]

However, system (13) is much more convenient to use than system (1). The characteristic equation of system (13) is written as follows:

$$(\mu) = \left\| \begin{array}{cccc} \mu & -1 & 0 & 0 \\ \omega^2 & \mu & 0 & 0 \\ 0 & 0 & \mu & -1 \\ 0 & 0 & \omega^2 & \mu \end{array} \right\| = 0 \quad (14)$$

Moreover, the roots of equation (14) are complex conjugates with multiplicity equal to two:

$$\mu_1 = +i\omega, \mu_2 = +i\omega, \mu_3 = -i\omega, \mu_4 = -i\omega.$$

Let us assume that  $\mu$  is one of the roots of this equation. Let us introduce the following substitution:

$$x_i = \exp\left\{\lambda \int_0^t \mu(t) dt\right\} z_i \quad (i = 1,2,3,4), \quad (15)$$

which transforms system (13) into the form:

$$\left. \begin{array}{l} \mu z_1 - z_2 = -\frac{1}{\lambda} \dot{z}_1, \\ \omega^2 z_1 + \mu z_2 = -\frac{1}{\lambda} [\dot{z}_2 + az_3], \\ \mu z_3 - z_4 = -\frac{1}{\lambda} \dot{z}_3, \\ \omega^2 z_3 + \mu z_4 = -\frac{1}{\lambda} [\dot{z}_4 + bz_1]. \end{array} \right\} \quad (16)$$

We find the solution to system (16) in the form of a series whose terms are arranged in inverse powers of the parameter  $\lambda$ :

$$z_i = z_{i0} + \frac{1}{\lambda} z_{i1} + \dots \quad (17)$$

To compute the functions  $z_{i0}$ , a system is formulated:

$$\left. \begin{array}{l} \mu z_{10} - z_{20} = 0, \\ \omega^2 z_{10} + \mu z_{20} = 0, \\ \mu z_{30} - z_{40} = 0, \\ \omega^2 z_{30} + \mu z_{40} = 0. \end{array} \right\} \quad (18)$$

Given that the equality  $\mu^2 = \omega^2$  holds, system (18) is always solvable, and two of the four unknowns may be chosen arbitrarily.[1],[9]

For the purposes of clarity, let us proceed on the supposition:

$$\mu = i\omega,$$

then

$$z_{20} = i\omega z_{10}, \quad z_{40} = i\omega z_{30}. \quad (19)$$

To find  $z_{i1}$ , a system of equations is formulated:

$$\left. \begin{array}{l} \mu z_{11} - z_{21} = -\dot{z}_{10}, \\ \omega^2 z_{11} + \mu z_{21} = -\dot{z}_{20} - az_{30}, \\ \mu z_{31} - z_{41} = -\dot{z}_{30}, \\ \omega^2 z_{31} + \mu z_{41} = -\dot{z}_{40} - bz_{30}. \end{array} \right\} \quad (20)$$

The system (20) breaks down into two independent systems of equations. The determinants of each system are zero. Applying the conditions for the solvability of the systems leads to a system of two 1<sup>st</sup>-order differential equations

$$\left. \begin{array}{l} -\dot{z}_{10}\omega^2 + \mu\dot{z}_{20} + a\mu z_{30} = 0, \\ -\dot{z}_{30}\omega^2 + \mu\dot{z}_{40} + b\mu z_{10} = 0. \end{array} \right\} \quad (21)$$

Applying substitution (19), the system (21) is transformed into a system of the form:

$$\left. \begin{array}{l} -2\dot{z}_{10}\omega^2 - \omega\dot{z}_{10} + ia\omega z_{30} = 0, \\ -2\dot{z}_{30}\omega^2 - \omega\dot{z}_{30} + ib\omega z_{10} = 0. \end{array} \right\} \quad (22)$$

Let's introduce one more substitution:

$$z_{10} = iz_{10}^*,$$

after which system (22) will have the entry:

$$\left. \begin{array}{l} -2\dot{z}_{10}^*\omega^2 - \omega\dot{z}_{10}^* + a\omega z_{30} = 0, \\ -2\dot{z}_{30}^*\omega^2 - \omega\dot{z}_{30}^* - b\omega z_{10}^* = 0. \end{array} \right\} \quad (23)$$

Next, let us set a value for  $\mu$ :

$$\mu = -i\omega,$$

then

$$z_{20} = -i\omega z_{10}, \quad z_{40} = -i\omega z_{30}. \quad (24)$$

In conclusion, we have the following equations:

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$$\begin{aligned} -2\dot{z}_{10} - \omega\dot{\omega}z_{10} - i b \omega z_{30} &= 0, \\ -2\dot{z}_{30} - \omega\dot{\omega}z_{30} - i b \omega z_{10} &= 0. \end{aligned}$$

By applying a substitution:

$$z_{10} = -iz_{10}^*,$$

The system will again be reduced to system (23). The equations of system (23) are first-order linear equations. Let us introduce the following notation:

$$z_1^{*(1)}, z_3^{(1)}, z_1^{*(2)}, z_3^{(2)}$$

for the system's fundamental solutions. In the general case, these solutions cannot be obtained either by quadrature or, even less so, in explicit form. However, the solutions to system (23) are slowly varying functions that can be fully determined using numerical methods. [1],[10]

Let us proceed to the construction of the system of fundamental solutions for equation (13). Here, it must be noted that the functions:

$$\begin{aligned} z_{11}^* &= iz_1^{*(1)} \exp \left\{ i\lambda \int_0^t \omega(t) dt \right\}, \\ z_{31}^* &= z_3^{(1)} \exp \left\{ i\lambda \int_0^t \omega(t) dt \right\} \end{aligned}$$

$$\begin{aligned} x_1 &= A \sin \left\{ \lambda \int_0^t \omega(t) dt \right\} z_1^{*(1)}(t) + B \cos \left\{ \lambda \int_0^t \omega(t) dt \right\} z_1^{*(1)}(t) + \\ &+ C \sin \left\{ \lambda \int_0^t \omega(t) dt \right\} z_1^{*(2)}(t) + D \cos \left\{ \lambda \int_0^t \omega(t) dt \right\} z_1^{*(2)}(t), \\ x_3 &= -A \cos \left\{ \lambda \int_0^t \omega(t) dt \right\} z_3^{(1)}(t) + B \sin \left\{ \lambda \int_0^t \omega(t) dt \right\} z_3^{(1)}(t) - \\ &- C \cos \left\{ \lambda \int_0^t \omega(t) dt \right\} z_3^{(2)}(t) + D \sin \left\{ \lambda \int_0^t \omega(t) dt \right\} z_3^{(2)}(t). \end{aligned}$$

Analogous expressions are derived for the variables  $x_2$  and  $x_4$ . In (25), A, B, C and D are designated as arbitrary constants.

Consequently, the implementation of asymptotic methods has facilitated the numerical integration of

and functions

$$\begin{aligned} z_{12}^* &= -iz_1^{*(1)} \exp \left\{ -i\lambda \int_0^t \omega(t) dt \right\}, \\ z_{32}^* &= iz_3^{(1)} \exp \left\{ -i\lambda \int_0^t \omega(t) dt \right\} \end{aligned}$$

are particular solutions of system (13). Instead of these functions, let us consider others:

$$\begin{aligned} x_{11} &= -\frac{z_{11}^* + z_{12}^*}{2} = \sin \left\{ \lambda \int_0^t \omega(t) dt \right\} z_1^{*(1)}, \\ x_{31} &= -\frac{z_{31}^* + z_{32}^*}{2} = -\cos \left\{ \lambda \int_0^t \omega(t) dt \right\} z_3^{(1)}, \\ x_{12} &= \frac{z_{11}^* - z_{12}^*}{2} = \cos \left\{ \lambda \int_0^t \omega(t) dt \right\} z_1^{*(1)}, \\ x_{32} &= \frac{z_{31}^* - z_{32}^*}{2} = \sin \left\{ \lambda \int_0^t \omega(t) dt \right\} z_3^{(1)}. \end{aligned}$$

By continuing the calculations in this manner, the remaining particular solutions are found. Ultimately, we obtain an asymptotic representation of the general solution (25):

the fourth-order system (11) with a rapidly oscillating solution, thereby yielding a numerical solution to the second-order system (23) with respect to the 'slow' variables.

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## THE DEGREE OF STUDENT FATIGUE FROM SENSORY-MOTOR FACTORS INHIBITING REACTIONS DURING COMPUTER-BASED EXERCISES

**Abstract:** The study analyses students' work on a PC during practical lessons simulating the functional elements of an electronic device. A cognitive model has been developed for the effect of delayed reactions on student fatigue when performing computer tasks in the presence of stimulating factors. A formula for the student's fatigue level has been derived:  $y_1=0,8385*(z_1)+(0,1778)*(z_2)+(-0,9491)*(z_3)+(-0,9491)*(z_4)$ . Constructed based on the values of variability of each term, the AI formulated a specific phrase of its meaning:  $meaning(y_1)$  = "the magnitude of the degree of fatigue of a student in the  $i$ -th lesson is equal to the sum of: a) the product  $c_{11}*z_{i1}$  (with the strength of manifestation  $c^2_{11}=(0,8385)^2$  of the slowing down of influences from team members); b) the product  $c_{21}*z_{i2}$  (with the strength of  $c^2_{21}=(0,1778)^2$  of the slowing down due to the student working on the same computer in all lessons; c) the product  $c_{31}*z_{i3}$  (with the strength of  $c^2_{31}=(-0,9491)^2$  of the acceleration due to the presence of the Data Base collected by him; d) the product  $c_{41}*z_{i4}$  (with the strength of  $c^2_{41}=(-0,9491)^2$  of the acceleration due to the decrease in the spread of preferences in the incentives of students in a group).

**Key words:** the degree of fatigue of the learner, slowing reactions when performing tasks on the computer, stimulating factors in the learner, cognitive model of the process, Inverse Principal Component Model.

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### ВЕЛИЧИНА СТЕПЕНИ УТОМЛЕНИЯ ОБУЧАЮЩЕГОСЯ ОТ ЗАМЕДЛЯЮЩИХ ФАКТОРОВ СЕНСОРНО-МОТОРНЫХ РЕАКЦИЙ ПРИ ВЫПОЛНЕНИИ КОМПЬЮТЕРНЫХ ПРАКТИКУМОВ

**Аннотация:** Анализируется ситуация «работа обучающихся на ПК на практических занятиях по имитации функциональных элементов прибора электроники». Разработана когнитивная модель процесса «влияние на степень утомления обучающегося от замедляющих реакций при выполнении заданий на компьютере при наличии стимулирующих факторов у обучающегося». Выведена формула величины степени утомления обучающегося:  $y_1=0,8385*(z_1)+(0,1778)*(z_2)+(-0,9491)*(z_3)+(-0,9491)*(z_4)$ . Сконструирована обоснованная значениями изменчивости каждого слагаемого, ИИ сформулировал специфическую фразу ее смысла:  $смысл(y_1)$  = «величина степени утомления обучающегося на  $i$ -ом уроке равна сумме: а) произведения  $c_{11}*z_{i1}$  (с силой проявления  $c^2_{11}=(0,8385)^2$  замедления влияний от членов коллектива; б) произведения  $c_{21}*z_{i2}$  (с силой  $c^2_{21}=(0,1778)^2$  проявления замедления от работы обучающегося на одном и том же компьютере на всех занятиях; в) произведения  $c_{31}*z_{i3}$  (с силой  $c^2_{31}=(-0,9491)^2$  проявления ускорения от наличия собранной им БД; г) произведения  $c_{41}*z_{i4}$  (с силой  $c^2_{41}=(-0,9491)^2$  проявления ускорения от уменьшения разброса предпочтений в стимулах обучающихся в группе».

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**Ключевые слова:** величина степени утомления обучающегося, замедляющие реакции при выполнении заданий на компьютере, стимулирующие факторы у обучающегося, когнитивная модель процесса, Обратная Модель Главных Компонент.

### Введение

В современном цифровом мире среди студентов распространилась проблема недостаточной физической активности и гиподинамии, негативные сенсорно-моторные реакции от работы с компьютерными программами. Неизбежен переход к применениям ПК в учебном процессе вуза. Смена формы проведения занятий. Устаревает традиционная форма практикума: имея тела элементов электроники, детали, бумажный рисунок схемы соединений деталей, проверочные приборы вручную собирались узлы или приборы электроники. Теперь на экране монитора «собирают» имитирующий работу некоторого изделия виртуальный образ (функциональную схему) с узлами и линиями соединений, имитирующий функцию стандартного электронного прибора или узла некоторого устройства. Традиционный подход требует больших материальных и временных затрат. Поэтому необходим переход к смене формы проведения занятий. В статье [1] «предлагается в ходе проведения компьютеризированных лабораторных практикумов использовать программное обеспечение для контроля времени сенсорно-моторных реакций обучаемого. Слишком активное погружение в виртуальный мир значков, меню, что приводит к сенсорной неудовлетворенности и может вызвать различные дисфункции органов чувств (глаза, уши), а мозг обучающегося – дать сигнал об умственном утомлении (не усталости). Умственное утомление — это временное снижение когнитивных функций (памяти, внимания, скорости мышления), вызванное длительной напряженной интеллектуальной работой. Симптомы включают снижение продуктивности, раздражительность, головные боли и иногда постоянную усталость, не проходящую после сна. Основные причины: стресс, многозадачность, нехватка отдыха. Мы не рассматриваем тактильные дисфункции: гиперчувствительность, недостаточная чувствительность; вестибулярные дисфункции: пониженный мышечный тонус, включая органы речи, нарушение координации движений; аудиальные дисфункции: повышенная реакция на громкие, резкие звуки (страх, тревога, истерика) или недостаточная реакция на звуки; артикуляционные дисфункции: трудности с определением источника звука, с распознаванием знакомых голосов, неразвитая устная речь, невнятное произношение. Ограничивающим ресурсом для обучающегося является время выполнения действий его пальцев, управляющих

роликом мышки на коврик, курсоров на экране. Замедление движений, замедление мозговых реакций - составляющие общего замедления работы за компьютером. Недостаточное сенсорно-моторное развитие осложняет адаптацию в социуме, замедляет его психическое и физическое развитие, влияет на дальнейшую успеваемость в вузе. Обучающийся — это лицо, которое в установленном порядке зачислено в учебное заведение и осваивает образовательную программу (школьную, вузовскую, профессиональную). При долгой концентрации внимания на экране компьютера наблюдается повышенная активность в затылочной и височных долях головного мозга, что приводит к быстрому утомлению [1]. Соответственно закономерна постановка вопроса о временах проявления факторов, вызывающих умственное утомление у обучающегося, вопроса о смене характера работы, но без перехода от использования компьютерного комплекса на классический аудиторный метод решения задач без компьютера. Мотивированная работа за компьютером увеличивает эффективность когнитивной (познающей) деятельности обучающегося. Авторами статьи [1] в ходе проведения лабораторных и практических занятий по курсу электроники была предпринята попытка прогнозирования изменения степени утомления обучаемого на основе контроля времени его сенсорно-моторных реакций (дестабилизирующих). Суть методики, положенной в основу компьютерной диагностики степени утомления состоит в случайном предъявлении комплекса стимулов, выбранных обучаемым и построении индивидуальных статистических оценок временных рядов для каждого обучаемого. В ранее использованной методике обеспечивался контроль времени либо только аудио-моторной или только времени зрительно-моторной реакций. В качестве программно-аппаратной поддержки применялось авторское программное обеспечение и комплекс компании «Нейролаб». Ниже предлагается оценка величины степени утомления обучающегося от замедляющих 4-х факторов сенсорно-моторных от реакций [1] при выполнении компьютерных практикумов.

### Исходные данные

Необходимо использовать как стимулы обучающегося, так и дестабилизирующие сенсорно-моторные факторы для определения величины степени утомления обучающегося по 25 значениям времени 4-х реакций. Исходные данные для познающей модели, теоретически

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обосновывающей искомую оценку, следующие.

Применим 2 стимулирующих и 2 дестабилизирующих факторов для оценки величины степени утомления обучающегося. Это дало возможность (как показало решение системы 4-смысловых уравнений) более обоснованной оценки степени умственного утомления обучающегося. 2 дестабилизирующие факторы использовались в процессе апробации методики компьютерной диагностики процесса «сенсорно-моторной реакции обучающихся при выполнении компьютерных лабораторных практикумов» [1]. Зависимые дестабилизирующие факторы процесса «сенсорно-моторной реакции обучающегося имеют смысл, соответствующие числовым коррелированным значениям  $z$ -переменных:

1) смысл( $z_1$ )=«замедляющее влияние членов коллектива (одноруппников) обучающихся на индивидуальные показатели времени обучающегося, связанное с отвлечением внимания обучающегося от стимулов (позитивных) познания». Замечание: знак коэффициента корреляции равен минусу, ибо характеризует связь замедляющего временного фактора с убыстряющимся фактором «познание» ( $c_{11} = \text{corr}(z_1, y_1) < 0$ ).

2) смысл( $z_2$ )=«необходимость независимой работы обучающегося индивидуально на одном и том же компьютере (наличие собранной им БД) во время практических занятий, проводимых для всех обучающихся». Замечание: работа обучающегося индивидуально на одном и том же компьютере (наличие собранной им БД) положительно способствует замедлению времени утомления от работы за этим компьютером обучающегося, т.е. коэффициент корреляции  $\text{corr}(z_1, z_2) = +0.5$  правильно отражает значение «веса» этой парной связи. Знак плюс отражает «замедление времени утомления», знак минус – убыстрение времени утомления.

3) смысл( $z_3$ )=«необходимость для обучающегося (независимого от других) накопления данных для построения требуемых (по учебной программе) моделей, что не позволяет на первых занятиях со всеми обучающимися выполнить Образовательную Программу в запланированные сроки». Замечание: чем больше собрано данных (в БД), тем меньше время наступления утомления при практической работе с готовыми данными: ниже в модели этот коэффициент корреляции  $\text{corr}(z_3, y_1)$  имеет знак минус и равен  $-0.1332 < 0$ .

4) смысл( $z_4$ )=«значительный разброс среднего времени работы в группе и разброс предпочтений в стимулах обучающегося в группе обучающихся».

Замечание: чем больше разброс предпочтений всех обучающихся (менее

целеустремлены согруппники), тем меньше утомляемость обучающегося, ( $\text{corr}(z_4, y_1) = -0.1332 < 0$ ). Этот коэффициент корреляции  $\text{corr}(z_4, y_1)$  должен иметь знак минус ( $c_{41} = \text{corr}(z_4, y_1) < 0$ ).

Эти замедляющие факторы сенсорно-моторных реакций ( $z_3, z_4$ ) при стимулированных ( $z_1, z_2$ ) действиях во время компьютерных практикумов обучающимся позволяют, как показано ниже, вычислить величину степени утомления обучающегося.

### Формализация процесса «влияние на степень утомления обучающегося замедляющих реакций от работы на ПК при наличии стимулирующих факторов у обучающегося»

Для расчета индивидуальных оценок времен действия сенсорно-моторных реакций и оценок времени накопления обязательных ресурсов, но замедляющих работу обучающегося, необходимо наличие измеренных значений показателей, характеризующих процесс «замедляющее влияние факторов сенсорно-моторных реакций обучающегося», очищенных от средних значений (оценок математического ожидания  $\mu$ ) времен проявлений «сенсорно-моторных реакций» очищенных от стандартных отклонений  $s$ :  $z = (x - \mu) / s$ ,  $x$ -измеренное значение. Для расчета степени утомления от этих негативных  $z$ -факторов будем использовать градацию шкалы Чэддока.

Для работы обучающегося по новой компьютерной методике проводятся практикумы. Работа сопряжена с проявлениями сенсорно-моторных реакций обучающегося (замедляющих время работы до окончания урока) при умственном моделировании (за экраном ПК с управляемыми обучаемым фигурами, значками, клавишами, стрелками (с помощью мышки и курсора) имитирующих работы реальных элементов электроники. Таких «помощников» так много, что требуется много пальцевая эквилибристика. Тут уместен учет степени утомления обучающегося (в шкале порядка) из-за проявлениями сенсорно-моторных реакций (измеряемых в наиболее точной шкале числовых отношений (+, -, \*, \)), позволяющей сравнивать 2 силы проявлений на сколько, во столько раз слабее/сильнее одно относительно другого проявления). Значение нуля силы проявления ( $c=0$ ) должно соответствовать отсутствию проявления сенсорно-моторных реакций обучающегося, положительное значение ( $c > 0$ , справа от 0 на оси абсцисс) модельного «веса» ( $c$ ) проявления будет интерпретироваться как наличие степени утомления, проявленного с силой ( $c$  весом)  $c^2$ . Степень утомления измеряется именем интервала шкалы Чэддока, Основные значения шкалы Чэддока: 0,1-0,3 : Слабая; (0,3 –

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0,5]: Умеренная; (0,5 – 0,7]: Заметная (или средняя); (0,7 – 0,9]: Высокая; (0,9 – 0,99] (1,0): Весьма высокая (сильная). Эта эмпирическая шкала, используемая в статистике для качественной оценки силы (тесноты) связи между двумя количественными показателями, характеризуемыми коэффициентом корреляции ( $\text{corr}(*,*)$ ). Она (шкала) словесно интерпретирует значения «весов»  $c = \text{corr}(z, y)$ . Здесь фраза смысла( $z$ ) известна (смотрите ниже), а фраза смысла( $y$ ) не известна. Формально заданы фразы 4-х смыслов  $\text{смысл}(z_1)$ ,  $\text{смысл}(z_2)$ ,  $\text{смысл}(z_3)$ ,  $\text{смысл}(z_4)$ . Им соответствуют модельные смысловые формулы  $\text{смысл}(y_j) = c_{1j} * \text{смысл}(z_1) + c_{2j} * \text{смысл}(z_2) + c_{3j} * \text{смысл}(z_3) + c_{4j} * \text{смысл}(z_4)$ ,  $j=1, \dots, 4$ . Для этих модельных смысловых формул отдельно моделируется 2 пары матриц ( $Y_{m4}, Z_{m4}$ ), ( $C_{44}, \Lambda_{44}$ ). Применяемая модель предполагает существование 4-х у-переменных,  $\Gamma_k(Y_{m4}^T Y_{m4}) = \Gamma_k(\Lambda_{44}) = \Gamma_k\{\text{diag}(4, 0, 0, 0)\} = 1$ , из них только 1-ая у-переменная с дисперсией  $\lambda_1 = 4$  содержит полную информацию и интерпретируется (имеет смысл( $y_1$ )) фразой «утомляемость обучающегося от дестабилизирующих факторов процесса «сенсорно-моторных реакций во время компьютерных практических занятий дисциплины «устройства электроники»». В правых частях уравнений неизвестны ни значения параметров  $c_{1j}$ ,  $c_{2j}$ ,  $c_{3j}$ ,  $c_{4j}$ , ни фразы 4-х смыслов 4-х z-переменных. Смыслы у-переменных неизвестны, но зависят от известных 4-х смыслов  $\text{смысл}(z_1)$ ,  $\text{смысл}(z_2)$ ,  $\text{смысл}(z_3)$ ,  $\text{смысл}(z_4)$ . Неизвестные значения параметров  $c_{1j}$ ,  $c_{2j}$ ,  $c_{3j}$ ,  $c_{4j}$ ,  $c_{k1}$ ,  $c_{k2}$ ,  $c_{k3}$ ,  $c_{k4}$ , они образуют квадратную матрицу  $C_{44}$ , являющуюся матрицей собственных векторов неизвестной ковариационной матрицы  $W_{44}$  такой, что  $W_{44} C_{44} = C_{44} \Lambda_{44}$ ,  $C_{44}^T C_{44} \neq I_{44}$ ,  $C_{44} C_{44}^T = I_{44}$ ,

Повсеместное использование компьютерных лабораторных практикумов определяет актуальность разработки и применения методов и средств контроля состояния обучающегося, использующего программно-технический комплекс (с накоплением базы требуемых данных). С использованием этого комплекса и накопленных данных происходит утомительное выполнение обучающимся своих лабораторных работ. Факторами, проявление которых порождает утомление у обучающегося, являются фразы смыслов z-переменных  $\text{смысл}(z_1)$ ,  $\text{смысл}(z_2)$ ,  $\text{смысл}(z_3)$ ,  $\text{смысл}(z_4)$ . Им соответствуют, как показано ниже, модельные смысловые формулы  $\text{смысл}(y_j) = c_{1j} * \text{смысл}(z_1) + c_{2j} * \text{смысл}(z_2) + c_{3j} * \text{смысл}(z_3) + c_{4j} * \text{смысл}(z_4)$ ,  $j=1, \dots, 4$ . Практикум курса электроники в вузах РФ, РК в основном базируется на основе компьютерных программ, моделирующих имитации работ реальных элементов и устройств электроники, радиотехники, магнетроники,

электрические машины. В процессе работы на компьютере, например, осуществляется выбор и соединение электронных элементов на экране монитора с последующим снятием осциллограмм и частотных характеристик. взаимодействие с мелкими предметами: толстыми отрезками, стрелками, петельками, кнопками, концевыми значками, символами тумблеров, прочих фрагментов электроники.

Введем переменные в числовую модель. Утомление проявлялся с изменчивостью  $y_1$  (отклонения от нуля под влиянием изменчивостей z-факторов  $z_1, z_2, z_3, z_4$ . Изменчивости  $y_2, y_3, y_4$ ,  $y_1$  соответствуют величинам сил проявлений составных факторов в составе -фактора  $y_1$  (смотрите ниже). Эти 4 значения «весов»  $c_1, c_2, c_3, c_4$  функционально зависят от формулы изменчивости ( $=1$ ) у переменной  $1 * y_1 = c_1 * z_1 + c_2 * z_2 + c_3 * z_3 + c_4 * z_4$ , полученной сложением вышеприведенных 4-х z-изменяющихся «весов»  $c_1 * z_1, c_2 * z_2, c_3 * z_3, c_4 * z_4$ . Здесь реализовано числовое сложение, а не сложение смыслов (сложение семантических переменных смотрите ниже). Левая часть равенства  $1 * y_1 = c_1 * z_1 + c_2 * z_2 + c_3 * z_3 + c_4 * z_4$  равно проявлению (с абсолютным весом 1) величине «требования авторитета (проявленного с «весом», равным 1, при у-переменной (у-изменчивости):  $1 * y_1$ . Из словесного описания имеем ограничения на значения параметров и переменных модели. Они описаны в разделе «Оптимизационная задача».

Как формализовать (применяя ПМ ГК [2,3], в которой имеются 4 у-переменные, а не одна у-переменная), зависящегося управляемого) и переменные  $z_1, z_2$  (присущие процессу замедления времен), переменные  $z_2, z_3, z_4$  (присущие замедлению времен) «веса»  $c_2=1, c_3=1, c_4=1$  при переменных  $z_1, z_2, z_3, z_4$ . В других 3-х числовых уравнениях «веса» имеют не единичные значения:  $y_2=0,5000 * z_1$ ;  $\text{disp}(y_2) = 0,2500$ ;  $y_3=-0,1057 * z_1$ ,  $\text{disp}(y_3)=0,0112$ ;  $y_4=(-0,1057) * z_1$ .

Если бы «вес» имел знак плюс (минус), то z-переменная имела бы тенденцию возрастать (убывать). В окне «функции ограничений» процедуры Solver (надстройка «Поиск решения» в ЭТ Excel 2016) не будем вводить не очевидные ограничения на знаки компонент №3, №4 1-го псевдособственного вектора. (Рисунок 4). Только из смысловых уравнений видны эти знаки (смотрите ниже).

### Оптимизационная Задача

Оптимизационная Задача ( $I_{54}, \Lambda_{44}$ ) => ( $C_{44}, \Lambda_{44}$ ). Пусть элементы неизвестной матрицы  $C_{44}$  псевдособственных векторов из пары матриц ( $C_{44}, \Lambda_{44}$ ),  $\Lambda_{44} = \text{diag}(4, 0, 0, 0)$  удовлетворяют условиям: значения компонент №1, №4 1-го псевдособственного вектора имеют знак минус: -

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$1 < c_{11} < 0$ ,  $-1 < c_{41} < 0$ ; б) соблюдаются ограничения на матрицу псевдосообственных векторов вида  $C_{44}C_{44}^T = I_{44}$ ,  $C_{44}^T C_{44} = \pm I_{44}$ , где значения компонент 1-го псевдосообственного вектора являются линейной комбинацией неизвестных значения z-изменчивостей с с-параметрами:  $y_{i1} = c_{11} * z_{i1} + c_{21} * z_{i2} + c_{31} * z_{i3} + c_{41} * z_{i4}$ ,  $i=1, \dots, m$ ; в) выполнены условия однофакторности произведения матриц вида  $C_{44}\Lambda_{44}C_{44}^T$ , где  $C_{44}$  - матрица псевдосообственных векторов такая, что выполняются условия:  $C_{44}C_{44}^T = I_{44}$ ,  $C_{44}^T C_{44} \neq I_{44}$ ,  $\Lambda_{44} = \text{diag}(\lambda_1, \dots, \lambda_4) = \text{diag}(4.0000, 0, 0, 0)$  - заданная матрица собственных чисел. Ограничения а), б), в) сужают область поиска неизвестных составов наборов сил проявлений входят в формулы 4-х u-переменных и являются существенными параметрами когнитивной модели.

Матрица «весов»  $C_{44}$  является существенным объектом в матричном смысловом равенстве вида  $\text{смысл}(Y_{m4}) = \text{смысл}(Z_{m4}C_{44})$  - применяемой гипотезе в моделях из [3-15]. Модельная пара  $(C_{44}, \Lambda_{44})$  матриц входит [3-5, 16] в новую схему Обратной Модели Главных Компонент [21]:  $(C_{44}, \Lambda_{44}) \Rightarrow (Y_{m4}, Z_{m4})$ , где  $C_{44}$  - модельная матрица [17, 18] значений «весов» (матрица псевдосообственных векторов, диагональная матрица  $\Lambda_{44} = \text{diag}(4, 0, 0, 0)$  является матрицей собственных чисел, матрицы случайных чисел  $Y_{m4} = U_{m4}\Lambda_{44}^{1/2}$ ,  $Z_{m4} = Y_{m4}C_{44}^T$ )  $U_{m4}^T U_{m4} = I_{44}$  моделируются [17-21], интерпретируются как многомерные выборки [21] u-, z-изменчивостей. Элементы  $y_{1j}, y_{2j}, \dots, y_{mj}$  j-го столбца матрицы  $Y_{m4} = U_{m4}\Lambda_{44}^{1/2}$  (j-ая u-переменная,  $j=1, \dots, 4$ ) имеют среднее арифметическое, равное нулю:  $(1/m)(y_{1j} + y_{2j} + \dots + y_{mj}) = 0$ , и дисперсию равную  $\lambda_j$ :  $(1/m)(y_{1j}^2 + y_{2j}^2 + \dots + y_{mj}^2) = \lambda_j$ . Матрица псевдосообственных векторов  $C_{44}$  такая, что выполняются условия:  $C_{44}C_{44}^T = I_{44}$ ,  $C_{44}^T C_{44} \neq I_{44}$ , матрица псевдосообственных чисел  $\Lambda_{44} = \text{diag}(\lambda_1, \dots, \lambda_4) = \text{diag}(4.0000, 0, 0, 0)$  отличается наличием нулевых значений:  $\text{tr}(\Lambda_{44}) = \lambda_1 + \dots + \lambda_4 = 4.0000 + 0 + 0 + 0$ . Здесь одна матрица  $C_{44}$  из пары матриц  $(C_{44}, \Lambda_{44})$  моделировалась программой GRD2, исходя из начальных матриц  $(I_{44}, \Lambda_{44})$ , используя ограничения и управляющий параметр  $c_{12} = 0.5000$ . Эти моделируемые матрицы должны подчиняться равенствам:  $C_{44}C_{44}^T = I_{44}$ ,  $C_{44}^T C_{44} = \pm I_{44}$ ,  $\text{tr}(\Lambda_{44}) = \lambda_1 + \dots + \lambda_4 = 4$ ,  $\lambda_1 = 4$ ,  $c_{12} = 0.5000$  - регулируемый параметр  $= \text{corr}(z_1, y_2)$  - коэффициент корреляции между z-переменной  $z_1$  и u-переменной  $y_2 = c_{12} * z_1 + c_{22} * z_2 + c_{32} * z_3 + c_{42} * z_4$ . А псевдосообственному числу  $\lambda_1$  назначили значение 4 для того, чтобы ранг матрицы  $C_{44}\Lambda_{44}C_{44}^T$  был равен 1. Оно является условием существования одной линейной комбинации критерием однофакторности соответствующей многомерной выборки  $Y_{m4} = Z_{m4}C_{44}$  [21]. Введем в излагаемую ниже модель введены 4 семантических переменных (4 фраз смыслов) зависимых z-

факторов, им соответствуют модельно вычисленные коррелированные 4 числовые z-переменные, равные значениям отклонений z вправо/влево от 0 (изменчивости проявлений z-элементов). К заданным 4 именам-смыслам модельных z-переменных, добавим ограничения. Матрица  $C_{44}$  служит индикатором [16-19] наличия скрытых знаний, поэтому сформируем для будущей пары матриц  $(C_{44}, \Lambda_{44})$  2 начальные диагональные единичные матрицы  $(I_{44}, I_{44})$ . Применяемая процедура GRD2 (из надстройки "Поиск решения") после последовательных приближений преобразует матрицы  $(I_{44}, I_{44})$  в матрицы  $(C_{44}, \Lambda_{44})$ . Для процедуры GRD2, необходимы функции ограничений, помогающие процедуре GRD2 уменьшить работу при поиске решения (матрицы  $C_{44}$ ).

Заданы ограничения на значения параметров и переменных модели: а) знаки «весов»  $c_1 > 0$ ,  $c_2 < 0$ ,  $c_3 > 0$ ,  $c_4 > 0$ , б) значения весов  $c^2_1, c^2_2, c^2_3, c^2_4$  (силы  $c^2_1, c^2_2, c^2_3, c^2_4$ ) должны удовлетворять неравенству должны удовлетворять ограничению  $c^2_1 + c^2_2 + c^2_3 + c^2_4 > 1$  для того, чтобы 1-ый псевдосообственный вектор мог иметь значения (по абсолютной величине), близкие к 1. Решается Оптимизационная Задача:  $(I_{44}, \Lambda_{44}) \Rightarrow (C_{44}, \Lambda_{44})$ , ее целевая функция имеет вид  $c^2_{11} + c^2_{21} + c^2_{31} + c^2_{41}$ , которая максимизируется при ограничениях  $C_{44}C_{44}^T = I_{44}$ . Было опасение, что процедура GRD2 откажется искать решение  $(C_{44}, \Lambda_{44})$ . Используем ограничения:  $\lambda_1 + \dots + \lambda_4 = 4$  при изменяемых значениях 4\*4 элементов матрицы  $C_{44}$ , имеющей ограничения на свои элементы:  $C_{44}^T C_{44} = I_{44}$ ,  $\Lambda_{44} = (\lambda_1, \dots, \lambda_4)$ ,  $\text{tr}(\Lambda_{44}) = \lambda_1 + \dots + \lambda_4 = 4$ , но без ограничений на монотонность:  $\lambda_1 = 4$ ,  $\lambda_2 = \lambda_3 = \lambda_4 = 0$ . Особенность данной пары: матрицы псевдосообственных векторов  $C_{44}$  и матрицы псевдосообственных чисел - состоит в том, что они позволяют моделировать как коррелированные z-переменные (с положительными дисперсиями), так и некоррелированные u-переменные (с близкими к 0 значениями дисперсий). Применяемая процедура GRD2 (из надстройки "Поиск решения") после последовательных приближений преобразует матрицы  $(I_{44}, I_{44})$  в матрицы  $(C_{44}, \Lambda_{44})$ . Для процедуры GRD2, необходимы функции ограничений, помогающие процедуре GRD2 уменьшить работу при поиске решения (матриц  $C_{44}, \Lambda_{44}$ ). Обращаем внимание на важность знаков «весов». Знаки плюс имеют все «веса», только «вес»  $c_2$  отрицателен, так как уровень повиновения у учителя сохраняется долго. Знак при  $c_1$  положителен: он подчиняется авторитету до конца эксперимента, его ожидаемое значение равно, Оптимизационная Задача даст решение, используя имеющиеся ограничения. Знак плюс при «весе»  $c_3$  должно сохраняться, ибо направление проявления смысла «веса»  $c_3$  () противоположно направлению проявления

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смысла  $c_2$  (повиновению учителя авторитету). Знаки  $c_4 < 0$  (должен быть минус. Матрица  $Y_{m4} = Z_{m4}C_{44}$  модельных значений  $z_{kj}$  соответствует введенным  $z$ -,  $y$ -переменным  $y_{ij} = c_{1j} * z_{i1} + c_{2j} * z_{i2} + c_{3j} * z_{i3} + c_{4j} * z_{i4}$  и параметрам  $c_{kj}$  (из матрицы  $C_{44}$ ).

Постановка задачи. Заданы величины  $16 = 4 * 4$  «весов» (из матрицы псевдосообственных векторов  $C_{44}$ , соответствующей матрице собственных чисел  $\Lambda_{44} = \text{diag}(4, 0, 0, 0)$  проявлений, вычисленных в системе из 4 смысловых уравнений с семантическими переменными  $\text{смысл}(z_1), \dots, \text{смысл}(z_4)$ . Требуется найти семантическое решение  $\text{смысл}(y_1)$ , используя системы многосмысловых уравнений, соответствующих СЛАУ  $Y_{m4} = Z_{m4}C_{44}$ ,  $C_{44}C_{44}^T = I_{44}$ ,  $C_{44}^T C_{44} \pm I_{44}$ ,  $\Lambda_{44} = \text{diag}(4, 0, 0, 0)$ ,  $\lambda_1 = 4$ , ограничениями  $-1 < c_{11} < 0$ ,  $-1 < c_{41} < 0$ , и с управляющим параметром  $c_{12} = 0.5000$ .

**Конструирование фраз смысла у переменной в процессе «влияние на степень утомления обучающегося замедляющих реакций от работы на компьютере при наличии стимулирующих факторов у обучающегося»**

Для параметризации системы смысловых уравнений соответствующих числовым линейным уравнениям (неизвестным  $y$ -переменным, зависящих от наборов известных значений параметров  $c_{kj}$   $k$ -ых  $z$ -переменных  $z_k \in \{1, 2, 3, 4\}$ ), формализующих явлений повиновения в эксперименте Милгрэма используем столбцы матрицы  $C_{44}$  (Таблица 1). Имеющие собственные числа  $(4.000, 0.000, 0.000, 0.000)$  интерпретируются содержательно, отображают объем информации, содержащейся в  $k$ -ой  $z$ -переменной.

Система числовых линейных алгебраических уравнений (СЛАУ) после отбрасывания нулевых параметров):  
 $y_1 = 0,8530 * z_1 + 1,0000 * z_2 + 1,0000 * z_3 + 1,0000 * z_4$ ,  $\text{disp}(y_1) = 3,7277$ ;  
 $y_2 = 0,5000 * z_1$ ;  $\text{disp}(y_2) = 0,250$ ;  $y_3 = -0,1057 * z_1$ ,  
 $\text{disp}(y_3) = 0,0112$ ;  $y_4 = (-0,1057) * z_1$ ,  $\text{disp}(y_4) = 0,0112$ .

В теории искусственного интеллекта [3-15] популярен «принцип линейного мышления». Числовым уравнениям из СЛАУ соответствует матричное смысловое равенство вида  $\text{смысл}(Y_{m4}) = \text{смысл}(Z_{m4}C_{44})$ , где  $\text{смысл}(Z_{m4}) = \text{смысл}(z_1) \oplus \dots \oplus \text{смысл}(z_4)$ ,  $\text{смысл}(Z_{m4}C_{44}) = \text{смысл}(Z_{m4}c_1) \oplus \dots \oplus \text{смысл}(Z_{m4}c_4)$ ,  $c_1, \dots, c_4$  – псевдосообственные векторы. Линейное числовое равенство соответствует фразам смыслов каждой переменной, а сумма фраз смыслов семантических переменных  $\text{смысл}(z_1) \oplus \text{смысл}(z_2) \oplus \text{смысл}(z_3) \oplus \text{смысл}(z_4)$  должна соответствовать их суммарной фразе ( $\text{смысл}(y)$ ) без когнитивного диссонанса. смысловому линейному конструированию многосмысловых линейных уравнений, где линейность выражена через слагаемые фразы,

образующую новую осмысленную фразу. Подставим в равенство  $Y_{m4} = Z_{m4}C_{44}$  значения элементов матрицы  $C_{44}$  (Таблица 1). В теории разговорного языка искусственного интеллекта [3,4] популярен «принцип линейного мышления». Матричное смысловое равенство вида  $\text{смысл}(Y_{m4}) = \text{смысл}(Z_{m4}C_{44})$ , где  $\text{смысл}(Z_{m4}) = \text{смысл}(z_1) \oplus \dots \oplus \text{смысл}(z_4)$ ,  $\text{смысл}(Z_{m4}C_{44}) = \text{смысл}(Z_{m4}c_1) \oplus \dots \oplus \text{смысл}(Z_{m4}c_4)$  точно соответствует смысловому равенству и линейному числовому равенству  $Y_{m4} = Z_{m4}C_{44}$ . Линейное числовое равенство удовлетворяет смысловому линейному конструированию многосмысловых линейных уравнений, где линейность выражена через слагаемые фразы, образующую новую осмысленную фразу. Подставим в равенство  $Y_{m4} = Z_{m4}C_{44}$  значения элементов матрицы  $C_{44}$  (Таблица 1). Система независимых смысловых уравнений  $\text{смысл}(y_1) = 0,8530 * \text{смысл}(z_1) + 1,0000 * \text{смысл}(z_2) + 1,0000 * \text{смысл}(z_3) + 1,0000 * \text{смысл}(z_4)$ ,  $\text{смысл}(y_2) = 0,5000 * \text{смысл}(z_1)$ ;  $\text{смысл}(y_3) = -0,1057 * \text{смысл}(z_1)$ ;  $\text{смысл}(y_4) = (-0,1057) * \text{смысл}(z_1)$ .

Для ясности восприятия шагов извлечения знаний из смысловых равенств заметим: в модели выполнены ограничения (смотрите раздел Оптимизационная Задача) на знаки 8 значений параметров из матрицы  $C_{44}$ . Из этих ограничений для ИИ важны формулы  $c_{1j}^2 + c_{2j}^2 + c_{3j}^2 + c_{4j}^2 = 1$ ,  $c_{1j}^2 + c_{2j}^2 + c_{3j}^2 + c_{4j}^2 \neq 1$ ,  $j = 1, \dots, 4$ ,  $c_{12} = 0.5$  – управляющий параметр. Для  $j$ -ой  $y$ -переменной значения весов  $c_{1j}^2, c_{2j}^2, c_{3j}^2, c_{4j}^2$  (могут иметь значения, близкие к 1) «измеряют» силы проявлений с изменчивостями  $z_{i1}, z_{i2}, z_{i3}, z_{i4}$ , каждое слагаемое в формуле  $y$ -переменной имеет вид произведения  $c_{kj} * z_{ik}$  (отклонение  $z_{ik}$  от 0  $k$ -ой  $z$ -переменной, присущее «весу»  $c_{kj}$ ). Квадраты значений «весов»  $c_{1j}, c_{2j}, c_{3j}, c_{4j}$  интерпретируются как веса (доли целого)  $c_{1j}^2, c_{2j}^2, c_{3j}^2, c_{4j}^2$ , равные 4 силам проявлений каждого  $k$ -го  $z$ -фактора. Сумма  $c_{1j}^2, c_{2j}^2, c_{3j}^2, c_{4j}^2$  не равна 1, так как в столбцах матрицы  $C_{44}$  расположены взаимно ортогональные векторы, неединичных длин. Это – алгебраическое обоснование модельных ограничений:  $C_{44}C_{44}^T = I_{44}$ ,  $C_{44}^T C_{44} \neq I_{44}$ ,  $\Lambda_{44} = \text{diag}(\lambda_1, \dots, \lambda_4) = \text{diag}(4, 0, 0, 0)$ . Наборы из 4 весов измеряют силы проявлений в  $j$ -той  $y$ -переменной (с нулевой дисперсией):  $c_{1j}^2 + c_{2j}^2 + c_{3j}^2 + c_{4j}^2 = 1$ ,  $\text{disp}(y_j) = 0$ ,  $j = 2, \dots, 4$ . Нулевая дисперсия  $y$ -переменной означает неизменность значений  $y$ -переменной при постоянных значениях  $(c_{1j}, c_{2j}, c_{3j}, c_{4j})$ . Постоянные значения «весов»  $(c_{1j}, c_{2j}, c_{3j}, c_{4j})$  могут иметь ненулевую ( $y_{ii} * c_{j1} \neq 0$ ,  $y_{ii} \neq 0, i = 1, \dots, 30$ ) или нулевую ( $y_{ij} * c_{kj} = 0$ ,  $j = 2, \dots, 4$ ,  $y_{ij} = 0$ ,  $k = 1, \dots, 4$ ,  $i = 1, \dots, 30$ )  $y$ -изменчивость, но  $z$ -изменчивости всегда ненулевые, так как значение  $z_{ik}$  равно линейной комбинации элементов  $i$ -ой строки (где 1-ый ее элемент ненулевой) умножается на ненулевое значение «веса».

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Поэтому в ненулевые значения в столбца №1 из Таблицы 5 преобразуются в ненулевые элементы всех столбцов матрицы  $Z_{m4}$  (Таблица 6).

Найдем фразу для нового смысла из модельного уравнения  $y_1=0,8530*z_1+1,0000*z_2+1,0000*z_3+1,0000*z_4$ . Здесь мы имеем заданные фразы для смыслов  $z_1$ ,  $z_2$ ,  $z_3$ ,  $z_4$ . Найдем фразу для суммы фраз, удовлетворяющей смысловому равенству из правой части уравнения:  $y_1=0,8385*z_1+0,1778*z_2+1,0000*z_3+1,0000*z_4$ , где  $z_1$  = «замедляющее влияние членов коллектива (одноруппников) обучающихся на индивидуальные показатели времени обучающегося, связанное с отвлечением внимания обучающегося от стимулов (позитивных) познания»;  $z_2$  = «необходимость независимой работы обучающегося индивидуально на одном и том же компьютере (наличие собранной им БД) во время практических занятий, проводимых для всех обучающихся». Замечание: работа обучающегося индивидуально на одном и том же компьютере (наличие собранной им БД) положительно способствует замедлению времени утомления от работы за этим компьютером обучающегося, т е коэффициент корреляции  $c_{12}=\text{corr}(z_1,z_2)=+0.5$  правильно отражает значение «веса» этой парной связи. Знак плюс отражает «замедление времени утомления», знак минус – убыстрение времени утомления;  $z_3$  = «необходимость для обучающегося (независимого от других) повышения объема накопления данных для построения требуемых (по учебной программе) моделей, что не позволяет на первых занятиях со всеми обучающимися выполнить Образовательную Программу в запланированные сроки». Замечание: чем больше собрано данных (в БД), тем меньше время наступления утомления при практической работе с готовыми данными».  $z_4$  = «повышающийся значительный разброс среднего времени работы в группе и разброс предпочтений в стимулах обучающегося в группе обучающихся» (с изменяющейся силой проявления  $c_{41}^2$ ). Уточним термин: не-замедление = убыстрение = ускорение. Фраза смыслового уравнения  $z_1=0,8385*\text{смысл}(z_1)+(0,1778)*\text{смысл}(z_2)+(-0,9491)*\text{смысл}(z_3)+(-0,9491)*\text{смысл}(z_4)$  равна сумме фраз  $z$ -смыслов:  $z_1$  = «величина степени утомления обучающегося в  $i$ -ом уроке равна сумме:  $z_1$  = «величина степени утомления обучающегося на  $i$ -ом уроке равна сумме: а) произведения  $c_{11}*z_{11}$  (с силой проявления  $c_{11}^2=(0,8385)^2$  замедления влияний от членов коллектива; б) произведения  $c_{21}*z_{12}$  (с силой  $c_{21}^2=(0,1778)^2$  проявления замедления от работы обучающегося на одном и том же компьютере на всех занятиях; в) произведения  $c_{31}*z_{13}$  (с силой

$c_{31}^2=(-0,9491)^2$ ) проявления ускорения наличия собранной им БД; г) произведения  $c_{41}*z_{14}$  (с силой  $c_{41}^2=(-0,9491)^2$ ) проявления ускорения уменьшения разброса предпочтений в стимулах обучающихся в группе». Эта фраза соответствует Определению.

**Определение.** При проявлении 2-х сенсорно-моторных реакций и 2-х стимулирующих обучающегося  $z$ -факторов во время выполнения им компьютерного практикума величина степени утомления обучающегося равна линейной комбинации величин отклонений от нуля  $z$ -факторов с «весами»  $c_1, c_2, c_3, c_4$  при  $z$ -переменных  $z_1, z_2, z_3, z_4$   $\text{смысл}(y)=c_1*\text{смысл}(z_1)+c_2*\text{смысл}(z_2)+c_3*\text{смысл}(z_3)+c_4*\text{смысл}(z_4)$ , где для заданной дисперсии  $\lambda_1=4$  (из матрицы  $\Lambda_{44}=\text{diag}(4,0,0,0)$ ) моделируются значения  $z$ -переменных  $z_1, z_2, z_3, z_4$   $Z_{m4}=Y_{m4}C^T_{44}$ , где случайная матрица  $Y_{m4}=U_{m4}\Lambda^{1/2}_{44}$  имеет только 1 ненулевой столбец с смыслом  $\text{смысл}(y)$ .

Так как  $c_{21}^2+c_{31}^2+c_{41}^2=1$ , то равенства  $c_{21}^2=(0,1778)^2$ ;  $c_{31}^2=(-0,9491)^2$ ;  $c_{41}^2=(-0,9491)^2$  соответствуют неодинаковым долям сил проявлений  $z$ -факторов  $z_2, z_3, z_4$ . Но доля каждого  $z$ -фактора  $z_2, z_3, z_4$  сильнее проявлена в величине степени утомления обучающегося, чем доля фактора  $z_1$ , равная  $c_{11}^2=0,8385^2$ . По силе влияния фактор  $z_1$  относится к интервалу «высокая» -  $c_{11}^2=0,8385^2$  (0,7 – 0,9]. Динамика значений утомления влияющих факторов (они равны из-за однофакторности модели:  $\Lambda_{44}=\text{diag}(4,0,0,0)$ )  $c_{21}*z_{12}=c_{31}*z_{13}=c_{41}*z_{14}$ ,  $i=1, \dots, 25$ , за 25 занятий имеет убывающий тренд (Рисунок 3). Для 4-факторной модели этих равенств не будет. Значения «весов» для факторов  $z_2, z_3, z_4$  относятся к интервалу «высокая» (0,7 – 0,9] по шкале Чэддока.

Равенство по абсолютной величине свидетельствует об одинаковости на одном уроке 3-х замедляющих факторов. Этот недостаток модели исправляется при использовании 4-факторной модели.

### Моделирование числовых матриц $Y_{m4}$ , $Z_{m4}$ $u$ - и $z$ -переменных для системы из 4 многомысловых уравнений

Матрица  $Y_{m4}=Z_{m4}C_{44}$  модельных значений  $z_{kj}$  соответствует введенным  $z$ -,  $u$ -переменным  $y_{ij}=c_{1j}*z_{11}+c_{2j}*z_{12}+c_{3j}*z_{13}+c_{4j}*z_{14}$  и параметрам  $c_{kj}$  (из матрицы  $C_{44}$ ). Первая  $u$ -переменная моделирует проявления  $y_1$ , соответствующие величине степени, остальные  $u$ -переменные  $y_2, y_3, y_4$  будут интерпретированы, найдены их смыслы. Эта модель допускает существование скрытых 3-х  $u$ -факторов с нулевыми дисперсиями в математической числовой модели, где отдельно моделировались матрицы  $U_{m4}$  (из матрицы равномерно распределенных случайных чисел  $V^0_{m4}$  (Таблица 3)) и  $Y_{m4}$  [17] такие, что  $(1/m)U^T_{m4}U_{m4}=I_{44}$  (Таблица 4),  $Y_{m4}=U_{m4}\Lambda^{1/2}_{44}$

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	<b>GIF (Australia) = 0.564</b>	<b>ESJI (KZ) = 8.100</b>	<b>IBI (India) = 4.260</b>
	<b>JIF = 1.500</b>	<b>SJIF (Morocco) = 6.004</b>	<b>OAJI (USA) = 0.350</b>

(Таблица 5),  $\Lambda_{44} = \text{diag}(4, 0, 0, 0)$ , затем моделировалась матрица  $Z_{m4} = Y_{m4} C_{44}^T$  (Таблица 6). Матрица значений z-переменных  $z_1, z_2, z_3, z_4$   $Z_{m4} = Y_{m4} C_{44}^T$ ,  $C_{44}^T C_{44} = I_{44}$ ,  $C_{44} C_{44}^T = I_{44}$ . Матрицы  $Z_{m4}$  и  $Y_{m4}$  содержат модельные значения изменчивостей (отклонений от 0), соответствующих реальным z-факторам эксперимента. Матрица  $Y_{m4}^{(t)}$   $t=1, \dots, \infty$ , обеспечивает случайность значений y- и z-отклонений из матриц  $(Y_{m4}^{(t)}, Z_{m4}^{(t)})$ . В матрице  $Y_{m4}$  элементы 1-го столбца  $y_{1j}, y_{2j}, \dots, y_{mj}$  (j-ая y-

переменная имеет не нулевые значения, столбцы с номерами  $j=2, 3, 4$  имеют нулевые значения, ибо  $\Lambda_{44} = \text{diag}(4, 0, 0, 0)$ . Все столбцы матрицы  $Y_{m4} = U_{m4} \Lambda_{44}^{1/2}$  (Таблица 5) имеют среднее арифметическое, равное нулю:  $(1/m)(y_{1j} + y_{2j} + \dots + y_{mj}) = 0$ , дисперсию равную  $\lambda_j$ :  $(1/m)(y_{1j}^2 + y_{2j}^2 + \dots + y_{mj}^2) = \lambda_j$ ,  $j=1, \dots, 4$ , при этом сумма дисперсий равна 4:  $\lambda_1 + \dots + \lambda_4 = 4$ . Матрицы  $Z_{m4}$ ,  $Y_{m4}$  приведены в Таблицах 5 и 6.

**Таблица 1. Модельная матрица C44 псевдосо собственных векторов для матрицы собственных чисел  $\Lambda_{44} = \text{diag}(4.000, 0.000, 0.000, 0.000)$ , полученная таблицы-программы Оптимизационной задачи:  $(I_{44}, I_{44}) \Rightarrow (C_{44}, \Lambda_{44})$**

c1	c2	c3	c4	Сумма квадратов
0,8385	0,5000	-0,1532	-0,1532	1,0000
0,1778	0,9841	0,0000	0,0000	1,0000
-0,9491	0,0000	0,3150	0,0000	1,0000
-0,9491	0,2227	0,2227	0,0004	1,0000
2,5362	1,2680	0,1723	0,0235	4,0000

**Таблица 2. Начальные значения элементов Матрицы C44 до решения Оптимизационной Задачи  $(I_{44}, \Lambda_{44}) \Rightarrow (C_{44}, \Lambda_{44})$**

	1	2	3	4	
z1	1,0000	0,0000	0,0000	0,0000	1,0000
z2	0,0000	1,0000	0,0000	0,0000	1,0000
z3	0,0000	0,0000	1,0000	0,0000	1,0000
z4	0,0000	0,0000	0,0000	1,0000	1,0000
	1,0000	1,0000	1,0000	1,0000	4,0000
c12=	0,5000				

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JIF	= 1.500	SJIF (Morocco)	= 6.004	OAJI (USA)	= 0.350

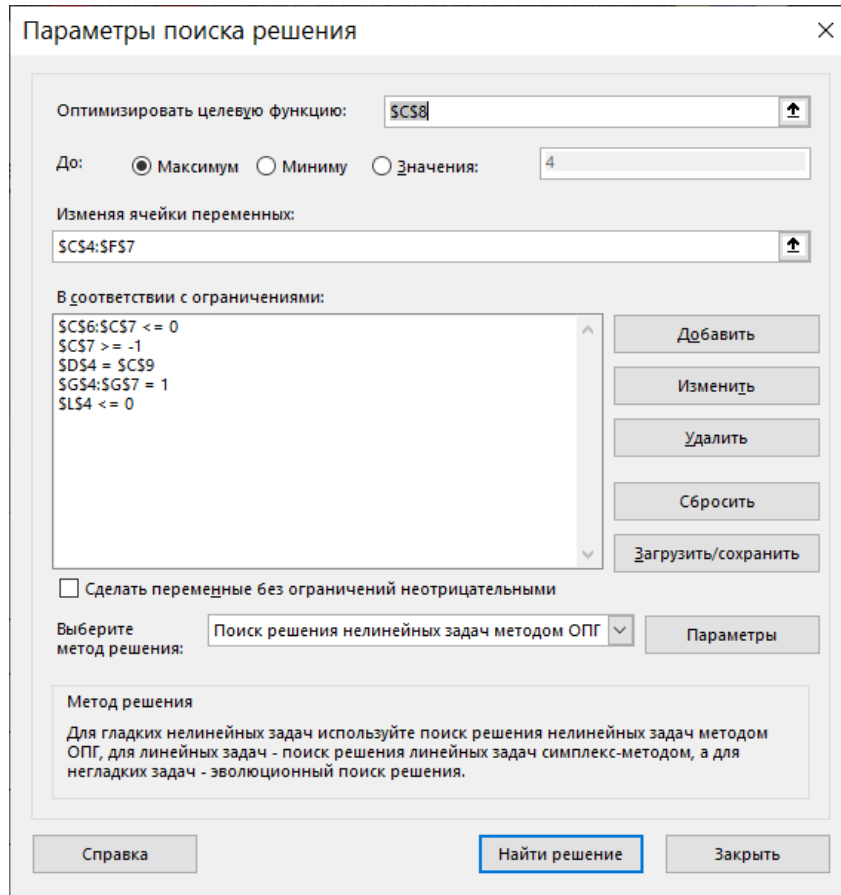


Рисунок 1. Вид таблицы-программы Оптимизационной задачи:  $(I_{44}, \Lambda_{44}) \Rightarrow (C_{44}, \Lambda_{44})$  в модели с 4 z-переменными, 4 y-переменными

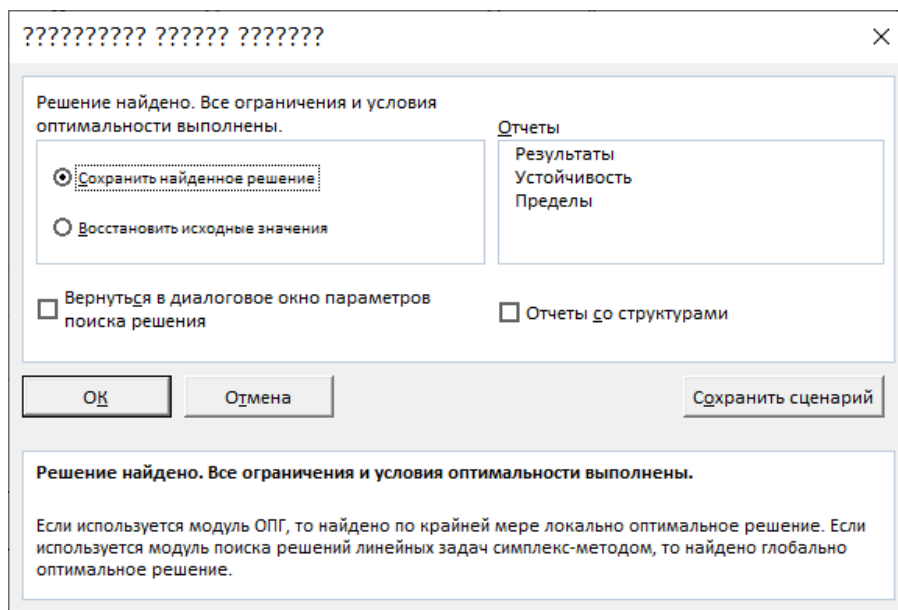


Рисунок 2. Вид таблицы-программы Оптимизационной задачи:  $(I_{44}, \Lambda_{44}) \Rightarrow (C_{44}, \Lambda_{44})$  в модели с 4 z-переменными, 4 y-переменными

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Таблица 3. Матрица  $V_{m4}^0$  значений равномерно распределенных в интервале [-1;1] случайных чисел

№	$v^0_1$	$v^0_2$	$v^0_3$	$v^0_4$
№	1	2	3	4
1	0,59752	-0,11362	-0,0309	0,813531907
2	-0,81872	-0,161534	0,1937	0,322733238
3	0,82727	0,211829	-0,3561	0,749748222
4	-0,2512	-0,765679	0,03146	0,772637104
5	-0,52898	0,6519059	0,15488	0,887447737
6	0,83117	-0,022492	0,40172	0,1515244
7	0,99792	-0,317728	0,42631	-0,60051271
8	-0,92633	0,6396374	0,06619	0,744804224
9	0,84094	0,1365093	0,55925	0,177953429
10	0,21494	-0,236793	0,12369	-0,9238258
11	-0,03244	-0,505234	0,9646	-0,56498917
12	-0,71844	-0,724052	-0,232	0,634815516
13	0,70025	0,4231391	0,74602	0,555467391
14	0,03397	0,1545152	-0,7044	0,851130711
15	-0,21384	-0,437666	-0,6675	-0,80260628
16	-0,33854	0,3386029	0,36387	0,323953978
17	0,71813	0,5672475	-0,6386	0,644398328
18	0,72771	0,8953215	-0,5018	0,296792505
19	-0,69573	-0,604541	0,81103	-0,59337138
20	0,36583	0,432783	0,85058	0,384624775
21	0,48924	-0,15305	0,38347	-0,92718284
22	0,72393	-0,235389	0,20664	0,550279244
23	0,42344	-0,647572	0,13779	0,411664174
24	0,66027	0,8239082	0,24418	-0,66905728
25	-0,21574	-0,986999	-0,6277	-0,27695547
	0,1765	-0,0255	0,1163	0,1566
	0,3844	0,2719	0,2474	0,3960

Таблица 4. Матрица  $U_{m4}$  u-изменчивостей

№	$u_1$	$u_2$	$u_3$	$u_4$
1	0,7084	-0,1693	-0,3043	1,0778
2	-1,6745	-0,2613	0,1602	0,2726
3	1,0949	0,4557	-0,9768	0,9732
4	-0,7196	-1,4213	-0,1753	1,0107
5	-1,1870	1,3007	0,0799	1,1991
6	1,1015	0,0057	0,5903	-0,0083
7	1,3820	-0,5612	0,6412	-1,2422

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<b>JIF</b> = <b>1.500</b>	<b>SJIF (Morocco)</b> = <b>6.004</b>	<b>OAJI (USA)</b> = <b>0.350</b>

8	-1,8555	1,2772	-0,1035	0,9651
9	1,1179	0,3111	0,9161	0,0350
10	0,0647	-0,4058	0,0154	-1,7727
11	-0,3515	-0,9212	1,7543	-1,1839
12	-1,5057	-1,3414	-0,7202	0,7846
13	0,8812	0,8614	1,3023	0,6544
14	-0,2398	0,3456	-1,6971	1,1395
15	-0,6568	-0,7915	-1,6207	-1,5738
16	-0,8666	0,6991	0,5121	0,2746
17	0,9113	1,1382	-1,5610	0,8003
18	0,9274	1,7681	-1,2780	0,2300
19	-1,4675	-1,1119	1,4367	-1,2305
20	0,3185	0,8800	1,5185	0,3741
21	0,5262	-0,2450	0,5526	-1,7782
22	0,9210	-0,4031	0,1869	0,6459
23	0,4155	-1,1946	0,0445	0,4185
24	0,8139	1,6310	0,2645	-1,3547
25	-0,6599	-1,8463	-1,5385	-0,7113
	0,0000	0,0000	0,0000	0,0000
	1,0000	1,0000	1,0000	1,0000

**Таблица 5. Матрица  $Y_{m4}$  у-изменчивостей**

№	y1	y2	y3	y4
1	1,4167309	0,0000	0,0000	0,0000
2	-3,348933	0,0000	0,0000	0,0000
3	2,1898188	0,0000	0,0000	0,0000
4	-1,439217	0,0000	0,0000	0,0000
5	-2,373947	0,0000	0,0000	0,0000
6	2,2029638	0,0000	0,0000	0,0000
7	2,7640893	0,0000	0,0000	0,0000
8	-3,711036	0,0000	0,0000	0,0000
9	2,2358262	0,0000	0,0000	0,0000
10	0,1293464	0,0000	0,0000	0,0000
11	-0,703099	0,0000	0,0000	0,0000
12	-3,011477	0,0000	0,0000	0,0000
13	1,7624023	0,0000	0,0000	0,0000
14	-0,479635	0,0000	0,0000	0,0000
15	-1,313518	0,0000	0,0000	0,0000
16	-1,73313	0,0000	0,0000	0,0000
17	1,8225815	0,0000	0,0000	0,0000
18	1,8548278	0,0000	0,0000	0,0000
19	-2,935072	0,0000	0,0000	0,0000

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20	0,6370705	0,0000	0,0000	0,0000
21	1,052369	0,0000	0,0000	0,0000
22	1,8420936	0,0000	0,0000	0,0000
23	0,8309586	0,0000	0,0000	0,0000
24	1,6278718	0,0000	0,0000	0,0000
25	-1,319885	0,0000	0,0000	0,0000
	0,0000	0,0000	0,0000	0,0000
	4,0000	0,0000	0,0000	0,0000

**Таблица 6. Матрица  $Z_{m4}$  z-изменчивостей**

№	$z_1$	$z_2$	$z_3$	$z_4$
1	1,1879	0,2518	-1,3446	-1,3446
2	-2,8080	-0,5953	3,1785	3,1785
3	1,8361	0,3893	-2,0783	-2,0783
4	-1,2067	-0,2558	1,3660	1,3660
5	-1,9905	-0,4220	2,2531	2,2531
6	1,8471	0,3916	-2,0908	-2,0908
7	2,3176	0,4913	-2,6234	-2,6234
8	-3,1116	-0,6597	3,5221	3,5221
9	1,8747	0,3974	-2,1220	-2,1220
10	0,1085	0,0230	-0,1228	-0,1228
11	-0,5895	-0,1250	0,6673	0,6673
12	-2,5250	-0,5353	2,8582	2,8582
13	1,4777	0,3133	-1,6727	-1,6727
14	-0,4022	-0,0853	0,4552	0,4552
15	-1,1014	-0,2335	1,2467	1,2467
16	-1,4532	-0,3081	1,6449	1,6449
17	1,5282	0,3240	-1,7298	-1,7298
18	1,5552	0,3297	-1,7604	-1,7604
19	-2,4610	-0,5217	2,7857	2,7857
20	0,5342	0,1132	-0,6046	-0,6046
21	0,8824	0,1871	-0,9988	-0,9988
22	1,5445	0,3275	-1,7483	-1,7483
23	0,6967	0,1477	-0,7887	-0,7887
24	1,3649	0,2894	-1,5450	-1,5450
25	-1,1067	-0,2346	1,2527	1,2527
	0,0000	0,0000	0,0000	0,0000
	2,8122	0,1264	3,6031	3,6031

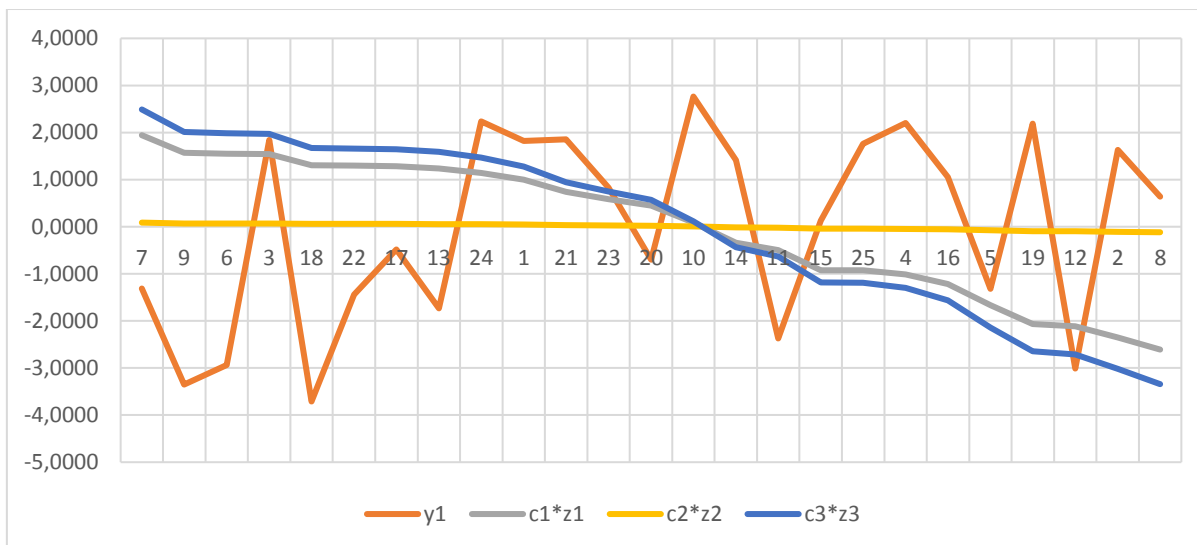
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	<b>GIF (Australia) = 0.564</b>	<b>ESJI (KZ) = 8.100</b>	<b>IBI (India) = 4.260</b>
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Таблица 7. Упорядоченные по убыванию значений сил степени утомления  $c_3 \cdot z_3$ , уменьшающиеся силы проявлений факторов  $c_1 \cdot z_1, c_2 \cdot z_2, c_3 \cdot z_3$  в течение 25 практических занятий на компьютере

$y_1$	$c_1 \cdot z_1$	$c_2 \cdot z_2$	$c_3 \cdot z_3$	№	
-1,3135	1,9433	0,0873	2,4898	7	
-3,3489	1,5719	0,0707	2,0140	9	
-2,9351	1,5488	0,0696	1,9844	6	
1,8421	1,5395	0,0692	1,9725	3	
-3,7110	1,3040	0,0586	1,6708	18	
-1,4392	1,2951	0,0582	1,6593	22	
-0,4796	1,2813	0,0576	1,6417	17	
-1,7331	1,2390	0,0557	1,5875	13	
2,2358	1,1445	0,0514	1,4664	24	
1,8226	0,9960	0,0448	1,2762	1	
1,8548	0,7399	0,0333	0,9480	21	
0,8310	0,5842	0,0263	0,7485	23	
-0,7031	0,4479	0,0201	0,5739	20	
2,7641	0,0909	0,0041	0,1165	10	
1,4167	-0,3372	-0,0152	-0,4320	14	
-2,3739	-0,4943	-0,0222	-0,6333	11	
0,1293	-0,9235	-0,0415	-1,1832	15	
1,7624	-0,9279	-0,0417	-1,1889	25	
2,2030	-1,0118	-0,0455	-1,2964	4	
1,0524	-1,2185	-0,0548	-1,5612	16	
-1,3199	-1,6690	-0,0750	-2,1384	5	
2,1898	-2,0635	-0,0927	-2,6439	19	
-3,0115	-2,1172	-0,0952	-2,7127	12	
1,6279	-2,3544	-0,1058	-3,0167	2	
0,6371	-2,6090	-0,1173	-3,3428	8	
0	0,0000	0,0000	0,0000		
4	2,8122	0,1264	3,6031		

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**Рисунок 3. Убывающиеся изменчивости  $((-0,9491)*z_3)$  для заметно сильно изменяющейся степени утомления ( $y_1$ ) обучающегося зависящей от  $z$ -переменных  $c_1*z_1, c_2*z_2, c_3*z_3, i=1, \dots, 25$ .**

### Заключение

Проведена формализация процесса «влияние на степень утомления обучающегося замедляющих реакций от работы на компьютере при наличии стимулирующих факторов у обучающегося». Введенные параметры, переменные численно измеряют, показывают во сколько раз проявление одного фактора больше/меньше проявления другого фактора. Это позволило вычислить все модельные силы проявлений (2 стимулирующих и 2 дестабилизирующих факторов) и оценить однодневные величины степени утомления одного обучающегося за 25 дней проведения практикумов с применением ПК. выражены численно в виде линейной комбинации значений  $16=4*4$  параметров при неизвестных 4-х  $z$ -переменных, выделена только 1 линейная комбинация, равная  $u$ -переменной  $y_1$ . В ней используются 4  $z$ -переменные (имеющих смыслы 2 – стимулирующие обучаемого и 2 смысла - дестабилизирующие) и найдена формула оценки величины степени утомления обучающегося. Найдены модельные отклонения параметров  $z_{i1}*c_{k1}$  ( $k$ -го фактора проявления (из 4), в  $i$ -ом практикуме. отдельно моделировались матрицы  $U_{m4}$  ( $\text{rang}(U_{m4})=4$ ) и  $Y_{m4}$  ( $\text{rang}(Y_{m4})=1$ ) [17] такие, что  $(1/m)U_{m4}^T U_{m4}=I_{44}, Y_{m4}=U_{m4}\Lambda^{1/2}_{44}, Z_{m4}=Y_{m4}C_{44}^T$  ( $\text{rang}(Z_{m4})=4$ ). Матрица значений  $z$ -переменных  $z_1, z_2, z_3, z_4$   $Z_{m4}=Y_{m4}C_{44}^T$ , имеет ковариационную, а не корреляционную матрицу, ибо ее псевдосообственные векторы удовлетворяют соотношениям  $C_{44}^T C_{44} \neq I_{44}, C_{44} C_{44}^T = I_{44}$ . Разработана

система многосмысловых уравнений с 4 семантическими неизвестными переменными, найдено одно ее решение в виде фразы из сложносочиненного предложения. Выведена формула величины степени утомления обучающегося:  $y_1=0,8385*(z_1)+(0,1778)*(z_2)+(-0,9491)*(z_3)+(-0,9491)*(z_4)$ . Сконструирована обоснованная значением изменчивости каждого слагаемого фраза ее смысла:  $\text{смысл}(y_1)=\langle \text{величина степени утомления обучающегося на } i\text{-ом уроке равна сумме: а) произведения } c_{11}*z_{i1} \text{ (с силой проявления } c_{11}^2=(0,8385)^2 \text{ замедления влияний от членов коллектива; б) произведения } c_{21}*z_{i2} \text{ (с силой } c_{21}^2=0,1778^2 \text{) проявления замедления от работы обучающегося на одном и том же компьютере на всех занятиях; в) произведения } c_{31}*z_{i3} \text{ (с силой } c_{31}^2=(-0,9491)^2 \text{) проявления ускорения от наличия собранной им БД; г) произведения } c_{41}*z_{i4} \text{ (с силой } c_{41}^2=(-0,9491)^2 \text{) проявления ускорения от уменьшения разброса предпочтений в стимулах обучающихся в группе} \rangle$ .

Модель обнаружила различие величин сил изменчивостей  $c_{11}^2=0,8385^2; c_{21}^2=(0,1778)^2; c_{31}^2=(-0,9491)^2; c_{41}^2=(-0,9491)^2$ , они соответствуют разным долям сил проявлений  $z$ -факторов  $z_1, z_2, z_3, z_4$ . По сравнению с долями  $z$ -факторов  $z_2, z_3, z_4$  немного слабее проявлена в величине степени утомления обучающегося доля фактора  $z_1$ , равная  $c_{11}^2=0,8385^2 < 1$  По силе влияния фактор  $z_1$  ( $c_{11}^2=0,8385^2$ ) относится к типу «высокая» - (0,7 – 0,9]. Динамика значений факторов  $z_3, z_4$ , влияющих на величину утомления (они равны из-за однофакторности модели:  $\Lambda_{44}=\text{diag}(4, 0, 0, 0)$ )

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$c_{31} * z_{i3} = c_{41} * z_{i4}$ ,  $i=1, \dots, 25$ , за 25 занятий имеет убывающий тренд (Рисунок 3).

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Article



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## INTERCULTURAL ASPECT OF INCLUSION IN MODERN EDUCATION

**Abstract:** The article examines the intercultural aspect of inclusion in the context of modern education, which is characterized by a high degree of cultural, linguistic, and ethnic diversity. Theoretical approaches to inclusion are analyzed, models of intercultural education are revealed, and the role of teachers in shaping an inclusive environment is explored. Particular attention is paid to the challenges of implementing inclusion in multinational societies, as well as to international experience in introducing intercultural educational practices. The necessity of a comprehensive approach to the development of intercultural competence among all participants in the educational process is emphasized. The study also analyzes theoretical approaches to inclusion under conditions of cultural diversity, highlights the role of teachers' intercultural competence, and examines the influence of sociocultural factors on the formation of an inclusive educational environment. It is emphasized that effective inclusion is impossible without taking into account the cultural, linguistic, and ethnic differences of learners.

**Key words:** inclusion, intercultural education, cultural diversity, pedagogy, intercultural competence, educational environment, tolerance.

**Language:** Russian

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### МЕЖКУЛЬТУРНЫЙ АСПЕКТ ИНКЛЮЗИИ В СОВРЕМЕННОМ ОБРАЗОВАНИИ

**Аннотация:** В статье рассматривается межкультурный аспект инклюзии в контексте современного образования, характеризующегося высокой степенью культурного, языкового и этнического разнообразия. Анализируются теоретические подходы к инклюзии, раскрываются модели межкультурного образования, исследуется роль педагогов в формировании инклюзивной среды. Особое внимание уделяется проблемам

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реализации инклюзии в многонациональных обществах, а также международному опыту внедрения межкультурных образовательных практик. Подчеркивается необходимость комплексного подхода к развитию межкультурной компетентности всех участников образовательного процесса. Анализируются теоретические подходы к инклюзии в условиях культурного разнообразия, раскрывается роль межкультурной компетентности педагогов, а также влияние социокультурных факторов на формирование инклюзивной образовательной среды. Подчеркивается, что эффективная инклюзия невозможна без учета культурных, языковых и этнических различий обучающихся.

**Ключевые слова:** инклюзия, межкультурное образование, культурное разнообразие, педагогика, межкультурная компетентность, образовательная среда, толерантность.

### Введение

Современный мир характеризуется усилением процессов глобализации, миграции и культурного взаимодействия. Эти процессы приводят к формированию многонациональных обществ, в которых образовательные системы сталкиваются с необходимостью учитывать разнообразие культурных, языковых и социальных характеристик обучающихся. В этих условиях образование становится «ключевым инструментом социальной интеграции и обеспечения равных возможностей для всех обучающихся независимо от их культурной принадлежности» [1, с.48].

Инклюзивное образование традиционно рассматривалось как «система включения лиц с ограниченными возможностями здоровья в образовательный процесс» [2, с.69]. Однако в последние десятилетия его содержание существенно расширилось. Сегодня инклюзия включает не только физические и когнитивные особенности обучающихся, но и их культурную, этническую и языковую идентичность.

В современном научном дискурсе его содержание расширяется и включает межкультурный компонент. Исследования показывают, что инклюзия тесно связана с межэтническим и межкультурным взаимодействием в образовательной среде.

Повышение многообразия среди учащихся и работников образования, представляющих разные реалии и культурные основы, требует инклюзивных - всё включающих и равноправных – учебных сред, которые поддерживают многообразие, удовлетворяют потребности всех учащихся и способствуют знанию и пониманию общих ценностей и принципов. «Инклюзивное образование нацелено на то, чтобы позволить всем обучающимся в полной мере реализовать свой потенциал посредством предоставления качественного образования для всех в самых распространенных условиях, уделяя особое внимание учащимся, которым может грозить маргинализация и низкая успеваемость, активно стремясь поддержать их и гибко реагируя на обстоятельства и потребности всех учащихся, в том числе и посредством индивидуальных подходов, целевой поддержки и сотрудничества с семьями и местными сообществами» [3, с.62].

### Методика экспериментов

Таким образом, возникает понятие межкультурной инклюзии, которое предполагает создание образовательной среды, учитывающей и уважающей культурное разнообразие.

Актуальность нашей статьи обусловлена тем, что без учета межкультурного фактора невозможно построить устойчивую и справедливую образовательную систему.

«Инклюзия (от лат. inclusion - включение) в педагогике означает процесс обеспечения равного доступа всех обучающихся к образованию, независимо от их индивидуальных особенностей» [5, с.72].

Современные исследователи выделяют три уровня инклюзии: физическая (доступ к образовательной среде), социальная (участие в жизни коллектива), культурная (признание и уважение идентичности). Именно культурная инклюзия становится центральным элементом межкультурного подхода.

Инклюзия тесно связана с концепцией мультикультурализма, предполагающей признание равной ценности всех культур. Однако между ними есть различие: мультикультурализм акцентирует сосуществование культур; инклюзия направлена на активное включение всех участников в единое образовательное пространство. Таким образом, инклюзия - более «деятельная и практико-ориентированная концепция» [6, с.62].

В настоящее время исследователи занимаются вопросами, связанными с межкультурным аспектом инклюзии. Межкультурная инклюзия представляет собой процесс создания образовательной среды, в которой учитываются культурные особенности обучающихся, обеспечивается равенство возможностей и формируется уважение к культурному разнообразию.

Её ключевые характеристики: признание культурной идентичности учащихся; предотвращение дискриминации; развитие диалога между культурами; формирование общей образовательной среды при сохранении культурных различий.

Межкультурная коммуникация является основным механизмом реализации инклюзии. Она включает в себя обмен культурными ценностями,

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развитие эмпатии, преодоление стереотипов, формирование навыков взаимодействия в многонациональной среде [7].

Без эффективной коммуникации инклюзия превращается в формальный процесс. Таким образом, инклюзия в образовательном контексте определяется как процесс создания условий, при которых все обучающиеся могут полноценно участвовать в образовательном процессе независимо от их особенностей. В более широком понимании она включает социальное и культурное разнообразие.

Современные исследования подчеркивают, что инклюзивное образование формирует среду равенства, где учитываются индивидуальные и культурные различия учащихся, обеспечивается доступ к обучению и социальной жизни [8-11].

Одной из основных задач инклюзии является реагирование на широкий спектр образовательных потребностей в школьной среде и за ее пределами. Инклюзивное образование основано на идеологии, исключающей любую дискриминацию детей, обеспечивающей равное отношение ко всем людям, но создающей особые условия для детей с особыми потребностями. Инклюзивное образование ценит разнообразие и уникальную роль каждого человека в образовательном процессе.

Межкультурный аспект инклюзии предполагает признание культурного многообразия как ценности, развитие толерантности и уважения к различным традициям, формирование навыков межкультурной коммуникации, адаптацию образовательных программ к культурным особенностям учащихся.

В современных условиях межкультурный аспект в инклюзивном образовании играет важную роль, вследствие чего межкультурную компетентность уместно рассматривать как основу инклюзии. Иными словами, одним из ключевых факторов успешной инклюзии является межкультурная компетентность педагогов. Она включает в себя знание культурных особенностей обучающихся, способность учитывать языковые различия, умение предотвращать культурные конфликты, навыки создания безопасной и уважительной образовательной среды.

Исследования в педагогических университетах показывают, что развитие инклюзивных ценностей напрямую связано с уровнем межкультурной подготовки будущих учителей.

Исследователи часто подчеркивают роль **этнокультурных факторов инклюзии** [12-14]. Этнокультурная среда оказывает значительное влияние на реализацию инклюзивного образования. В многонациональных обществах особое значение приобретают: язык обучения,

традиции и нормы поведения, религиозные особенности, уровень культурной интеграции, семейные ценности, социальные нормы поведения.

Например, сравнительные исследования показывают, что языковой фактор может как способствовать, так и препятствовать включению детей в образовательный процесс, то есть языковой барьер является одной из главных проблем инклюзии в многонациональных классах. Он может препятствовать не только обучению, но и социальной интеграции.

Нельзя оставлять без внимания вопросы практической **реализации межкультурной инклюзии**. В образовательной практике межкультурная инклюзия реализуется через внедрение мультикультурных образовательных программ, использование двуязычного обучения, развитие программ культурного обмена, применение технологий адаптивного обучения. Основные направления практической реализации инклюзивного образования. Это реализация образовательных программ через внедрение мультикультурного содержания, использование примеров разных культур, включение этнической истории. Сюда входит организация среды: создание безопасного пространства, визуальное отражение культурного разнообразия, поддержка языкового разнообразия. В процессе реализации можно эффективно использовать следующие методики обучения: кооперативное обучение, проектную деятельность, диалоговые технологии [15].

Особое значение имеет создание инклюзивной культуры образовательного учреждения, где ценится разнообразие и поддерживается равенство возможностей.

В условиях реализации межкультурной инклюзии возникает проблема подготовки компетентного педагога. Структура компетентности педагога включает в себя когнитивный компонент, то есть знание культурных особенностей, понимание этнопсихологии. Следующий компонент – это эмоциональный компонент: толерантность, эмпатия, уважение к различиям. Далее – поведенческий компонент, сюда относятся навыки общения, умение предотвращать конфликты, адаптация образовательных методов.

В настоящее время большое внимание уделяют подготовке педагогов. Современные педагогические программы всё чаще включают курсы по межкультурной педагогике, тренинги по толерантности, практику работы в мультикультурных группах.

Однако во многих странах подготовка остаётся недостаточной, что снижает эффективность инклюзии.

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Если говорить о международном опыте межкультурной инклюзии, то следует подчеркнуть, что в странах Европы активно развиваются модели интеграции мигрантов через образование, билингвального обучения, межкультурных школьных программ. Особое внимание уделяется языковой поддержке учащихся-мигрантов. В США реализуется концепция *inclusive multicultural education*, которая предполагает равный доступ к образованию, учет этнического разнообразия, борьбу с дискриминацией в школах.

В странах Азии акцент делается на сохранение национальной идентичности, гармонизацию традиций и современных образовательных подходов, развитие межэтнического согласия.

Интенсивное развитие межкультурной инклюзии породило множество проблем. Так, несмотря на развитие инклюзивных практик, сохраняются следующие проблемы: недостаточная подготовка педагогов, языковые барьеры, культурные стереотипы и предубеждения, ограниченность методических ресурсов.

Особенно сложной является проблема адаптации образовательных программ к быстро меняющемуся культурному составу учащихся. Также часто наблюдается формальный характер внедрения инклюзии без глубокой перестройки образовательной среды.

Межкультурная инклюзия имеет хорошие перспективы развития. Будущее межкультурной

инклюзии связано с цифровизацией образования, развитием адаптивных технологий, внедрением искусственного интеллекта в обучение, усилением международного сотрудничества.

Также важным направлением является формирование глобальной гражданской идентичности при сохранении культурного разнообразия.

### Заключение

Развитие инклюзии требует комплексного подхода, включающего педагогическую подготовку, изменение образовательных программ и формирование инклюзивной культуры. В условиях глобализации именно межкультурная инклюзия становится основой устойчивого социального развития. Межкультурный аспект инклюзии является ключевым элементом современного образования. Он обеспечивает не только доступ к знаниям, но и формирование гармоничного, толерантного общества.

Результаты исследования свидетельствуют о необходимости перехода от традиционных образовательных моделей к обучению, ориентированному на устойчивое мышление. Совершенствование содержания образования, активное использование цифровых технологий и повышение квалификации педагогов создают условия для подготовки поколения специалистов, способных вносить вклад в устойчивое развитие общества.

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Article



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## MODAL ANALYSIS AND D'ALEMBERT'S PRINCIPLE

**Abstract:** The objective of this study is to ascertain the characteristics of seismic actions that define their hazard level for various limit states of structures. In addition, a methodology for modelling design actions in multi-level structural design is to be developed. The present study employs methodologies from the fields of structural mechanics, structural dynamics, and mathematical statistics. The findings facilitate the evaluation of the seismic resilience of structures in scenarios where seismological data is scarce or non-existent, a crucial consideration for standard design methodologies. A comprehensive investigation and analysis of the kinematic, spectral and energy characteristics of seismic actions has been conducted. A methodology is proposed for determining the design action level, taking into account the seismic hazard of the area and the structure's service life. A new model for calculating accelerograms has been developed, taking into account the expected limit states of structures and the characteristics of actual earthquakes. A modal analysis of systems with many degrees of freedom was performed based on D'Alembert's principle.

**Key words:** Seismic response, response modeling, response intensity, deterministic method, probabilistic method, Arias intensity, absolute cumulative velocity, accelerogram, limit state, structural mechanics.

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### Introduction

In the study of a system with a single degree of freedom, the value of the restoring force was obtained by solving the equation of motion for a conservative system and was confirmed experimentally. It was also

established that the restoring force exactly follows Hooke's law. In subsequent calculations, the equation of equilibrium was essentially used.[1]-[3]

In 1743, a French mathematician proposed a statement that would subsequently become known as

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"D'Alembert's principle". In accordance with the aforementioned statement, it can be posited that all of the laws of motion of a system of material points can be reduced to the laws of equilibrium. In the event of a geometrically rigid system of material points with constraints being in equilibrium under the action of external loads, the following condition is to be observed:

$$F_{si} + P_i = 0 \{i = 1, 2, \dots, n\},$$

where  $F_{si}$  is the resultant reaction force;  $P_i$  — is the resultant of all external (active) forces acting on point  $i$ .

If the active force varies with time, then, according to Newton's second law, there is a change in momentum  $m_i \dot{y}_i = F_{si} + P_i$ .

If we input the force  $S_i = P_i - m_i \ddot{y}_i$ , known as the "lost force," then Newton's second law can be written as  $F_{si} + P_i = 0$ . This equation of motion is structurally identical to the equation of equilibrium. The lost force  $S_i$  can be expressed as the sum of two forces: the active force  $P_i$  and the so-called inertial force  $I_i = -m_i \ddot{y}_i$ . Then the equation of motion takes the form of an equilibrium equation for three forces

$$F_{si} + P_i + I_i = 0$$

An illustration of D'Alembert's idea is shown in Fig. 1. In Fig. 1a, a vector representation of Newton's law is shown; Fig. 1b illustrates the idea behind D'Alembert's principle; and Fig. 1c provides a visual representation of the lost force.

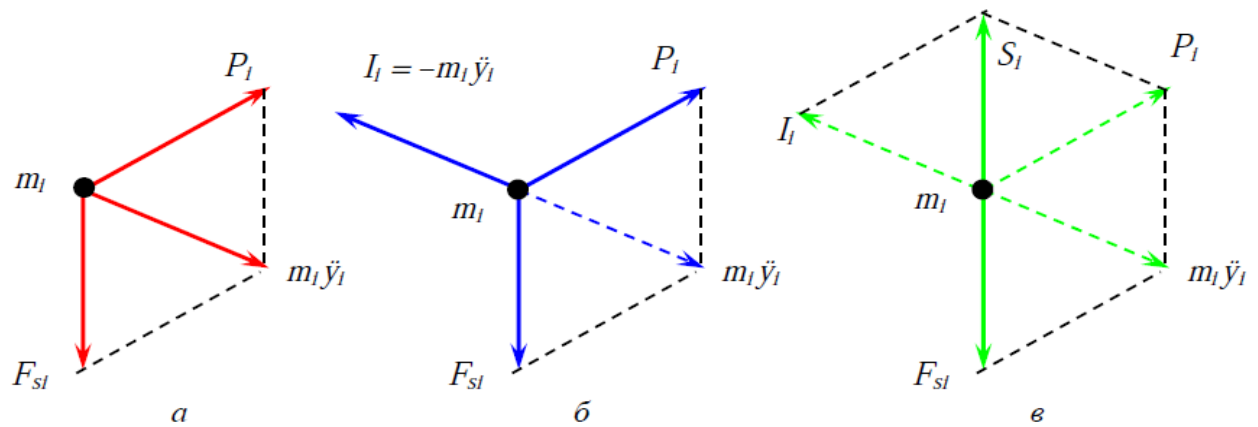


Fig. 1. D'Alembert's idea: *a* — a vector representation of Newton's law; *b* — D'Alembert's principle; *c* — lost force

D'Alembert generalized the equilibrium condition for a single point to an arbitrary mechanical system. According to D'Alembert's principle, the dynamic equilibrium condition can be obtained by adding the inertial force to the static equilibrium equation. The static equation for systems with many degrees of freedom is known from the course "Structural Mechanics":  $ry = P$ , where  $r$  — is the stiffness matrix of the system;  $y$  — is the desired displacements;  $P$  — is the external load.[2]

By adding the inertial force, we obtain the dynamic equilibrium equation

$$m \ddot{y} + ry = P.$$

We will proceed in the same way with the damping forces. Ultimately, the dynamic equilibrium equation for a system with many degrees of freedom under seismic loading will take the form

$$m \ddot{y} + c \dot{y} + ry = m \ddot{y}_0. \quad (1)$$

Equation (1) is identical to Equation (2.1), but is written in matrix form. Frequency analysis of the

equation of motion. The free oscillations of a conservative system with many degrees of freedom are described by the equation

$$m \ddot{y} + ry = 0, \quad (2)$$

where 0 is the zero vector.

By analogy with the analysis of a system with one degree of freedom, let us assume that the system undergoes harmonic oscillations

$$y = \hat{y} \sin(\omega t + \varphi_0) \quad (3)$$

where  $\hat{y}$  — is a vector characterizing the modes of oscillation of the system, in which only the amplitudes vary.

We differentiate (3) twice and substitute the result into (2)

$$(r - \omega^2 m) \hat{y} \sin(\omega t + \varphi_0) = 0$$

or, by omitting the term  $\sin(\omega t + \varphi_0)$ , we obtain

$$(r - \omega^2 m) \hat{y} = 0. \quad (4)$$

A non-trivial solution (4) for  $\hat{y}$  is possible provided that the determinant of the system is zero

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$$\|r - \omega^2 m\| = 0. \quad (5)$$

Equation (5) is called the frequency equation of the system. Expanding the determinant in (5) yields an equation of the  $n$ th degree in  $\omega^2$ . Solving this equation yields  $n$  values  $\omega$

$$\omega^T = (\omega_1, \omega_2, \dots, \omega_i, \dots, \omega_N),$$

where  $N$  is the number of degrees of freedom. When  $N \rightarrow \infty - \omega_{max} \rightarrow \infty$ .

The problem of finding the frequencies of oscillations corresponds to the problem of eigenvalues in linear algebra. Let us rewrite equation (4) in the form

$$r\hat{y} = \lambda m\hat{y} \quad (6)$$

where the following symbols are defined  $\lambda = \omega^2$

In terms of linear algebra, the quantities  $\lambda$  and  $\hat{y}$  are referred to as eigenvalues and eigenvectors, respectively. There are methods for determining the eigenvalues and eigenvectors directly from equation (3.6). If the mass matrix is diagonal, the problem is significantly simplified. Let us introduce the following notation

$$k = m^{-\frac{1}{2}} r m^{-\frac{1}{2}}, V = m^{\frac{1}{2}} \hat{y}$$

Then equation (6) can be written in standard form as  $\lambda = V^T k V$ , where  $\lambda$  is a diagonal matrix of eigenvalues;  $V$  — is a matrix whose columns are the eigenvectors of the matrix  $k$ . [1],[3]-[5]

Eigenvectors and eigenvalues have the following properties:

- 1) an eigenvector  $V_i$  has a unique eigenvalue  $\lambda_i$ ;
- 2) if  $V_i$  — is an eigenvector with eigenvalue  $\lambda_i$  and  $q$  — is any nonzero number, then  $qV_i$  — is also an eigenvector with eigenvalue  $\lambda_i$ ;
- 3) if  $V_i$  and  $V_j$  are eigenvectors with eigenvalues  $\lambda_i$  and  $\lambda_j$ , where  $\lambda_i \neq \lambda_j$ , then  $V_i$  and  $V_j$  are linearly independent;
- 4) The eigenvectors of a real symmetric matrix corresponding to different eigenvalues are orthogonal. A necessary and sufficient condition for orthogonality is  $V^T V = E$ , where  $E$  is the identity matrix. It follows that  $V^{-1} = V^T$ . The condition for orthogonality of vectors  $\hat{y}$

$$\hat{y}^T m \hat{y} = E \quad (7)$$

Vectors that satisfy condition (7) are called orthonormal. Let us multiply both sides of equation (6) on the left by the transpose of the eigenvector matrix

$$\hat{y}^T \cdot \hat{y}^T r \hat{y} = \omega^2 \hat{y}^T m \hat{y} \quad (8)$$

or taking into account (7)  $\hat{y}^T r \hat{y} = \omega^2$ , where  $\omega^2$  — is a diagonal matrix.

It should be noted that the values of  $\omega^2$  are not eigenvalues of the stiffness matrix  $r$ .

Standard coordinates. Let's enter generalized coordinates

$$y = \Phi q, \quad (9)$$

where  $\Phi$  — a matrix composed of columns of eigenvectors;  $q$  — a column vector of generalized (modal) coordinates. [1],[2]-[4]

Essentially, we have replaced the vector  $\hat{y}_i$  of the  $i$  th eigenmode with the vector  $q_i \varphi_i$ , where  $q_i$  — is a scalar. This substitution is possible thanks to the second property of eigenvectors. After substituting the generalized coordinates into the equation of motion (1), we obtain

$$m\Phi\ddot{q} + c\Phi\dot{q} + r\Phi q = m e \ddot{y}_0 \quad (10)$$

where  $e$  is the vector that determines the displacement of masses for a unit displacement of the base. Essentially, this is the vector of cosines between the direction of the seismic excitation and the directions of the dynamic degrees of freedom.

Multiplying both sides of the equation from the left by the transposed matrix of eigenvectors yields a system of decoupled equations

$$\Phi^T m \Phi \ddot{q} + \Phi^T c \Phi \dot{q} + \Phi^T r \Phi q = \Phi^T m e \ddot{y}_0,$$

where  $\Phi^T m \Phi, \Phi^T c \Phi, \Phi^T r \Phi$  diagonal matrices. Thus, for any  $i$ -th eigenmode, a unique equation is obtained in terms of the generalized coordinate  $q_i$

$$\varphi_i^T m \varphi_i \ddot{q}_i + \varphi_i^T c \varphi_i \dot{q}_i + \varphi_i^T r \varphi_i q_i = \varphi_i^T m e \ddot{y}_0 \quad (11)$$

Let's define the following notation:  $M_i = \varphi_i^T m \varphi_i$  - modal mass;  $C_i = \varphi_i^T c \varphi_i$  - modal damping;  $R_i = \varphi_i^T r \varphi_i$  - modal stiffness;  $L_i = \varphi_i^T m e$  - modal active mass.

Given the notation used, equation (11) takes the form

$$M_i \ddot{q}_i + C_i \dot{q}_i + R_i q_i = L_i \ddot{y}_0$$

Since the modal mass is nonzero, it can be eliminated from the equilibrium equation for the modal coordinate. Then, taking (8) into account, the equation for the  $i$ -th mode takes the form of a linear oscillator

$$\ddot{q}_i + 2\xi_i \omega_i \dot{q}_i + \omega_i^2 q_i = \frac{L_i}{M_i} \ddot{y}_0 \quad (12)$$

where  $\frac{L_i}{M_i}$  - seismic load factor. By analogy with a system having a single degree of freedom, the following symbols are defined:

$$\frac{C_i}{M_i} = 2\xi_i \omega_i, \quad \frac{R_i}{M_i} = \omega_i^2$$

The determination of the displacements  $y_j$  in geometric coordinates is achieved by solving equation (12) in terms of the generalized coordinates  $q_i$ , via transformation (9). As the generalized coordinates are obtained through orthogonal transformations of the original matrices, they are referred to as normal coordinates. Furthermore, it is important to note that

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generalized coordinates are used to characterise the principal modes of undamped systems and are also referred to as principal coordinates. The term 'modal' is ultimately derived from the Latin term 'modus', which translates to 'form', 'method' or 'rule'. This nomenclature is employed to denote the specific calculation method. The term 'normal' is most frequently employed, with the emphasis placed on the derivation of a decoupled system of equations.[6]

*Note:* For equation (12) to be correctly presented, two conditions must be met:

1) The damping matrix must satisfy the condition  $\varphi_i^T c \varphi_i = 2\xi_i \omega_i \varphi_i^T m \varphi_i$

2) The damping ratio must be much less than 1 for all eigenmodes. That is, the following condition must hold:  $\omega_i \approx \sqrt{1 - \xi_i^2}$ .

If the first condition is not satisfied, then it will not be possible to obtain decoupled equations, and the form decomposition loses its meaning. If the second condition is not satisfied, then the form decomposition does not reduce to an eigenvalue problem in linear algebra.

*Example 1.* Let us determine the periods and modes of vibration of the planar system shown in Fig. 2. The system has three degrees of freedom—two translational and one rotational. The translational degrees of freedom are associated with masses of 200 t, and the rotational degree of freedom with a mass of 150 тм<sup>3</sup>. The stiffness matrix of the system

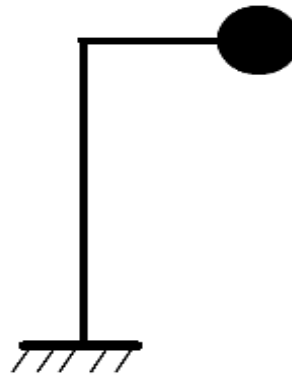


Fig. 2. Flat system

$$r = \begin{bmatrix} 70743 & 7949 & -9687 \\ 7949 & 55739 & 32901 \\ -9687 & 32901 & 60732 \end{bmatrix}$$

Matrix  $k = m^{-\frac{1}{2}} r m^{-\frac{1}{2}}$

$$k = \begin{bmatrix} 353,7154 & 39,747 & -55,93 \\ 39,7466 & 278,694 & 189,956 \\ -55,931 & 189,956 & 404,883 \end{bmatrix}$$

Let's define the eigenvalues  $k$  and the real eigenvectors  $\lambda = \{123 \ 369 \ 544\} \Phi = V m^{-\frac{1}{2}} =$   
 $\begin{bmatrix} -0,01927 & 0,06749 & -0,00859 \\ 0,05457 & 0,02067 & 0,03994 \\ -0,04692 & -0,00491 & 0,06664 \end{bmatrix}$ . Natural  
 frequency  $\omega = \{11,1 \ 19,2 \ 23,3\}$  и Periods by  
 waveform  $T_i = \frac{2\pi}{\omega_i}$ .  $T = \{0,566 \ 0,327 \ 0,269\}$ .

In this particular instance, the eigenvectors are orthonormalized. The calculations were performed in MS Excel using the application's functions.[1]

The phenomenon of superposition of vibration modes is demonstrated here. Following the determination of the system's response in normal coordinates, a transition is initiated to geometric coordinates. In accordance with the stipulations

outlined in Section 3.9, the displacement of the  $k$ -th mass is to be determined.

$$y_k = \sum_{i=1}^n q_i \varphi_{i,k} \quad (13)$$

where  $n$ — number of forms included. The modes are arranged in an ascending order of natural frequencies, or, alternatively, in a descending order of vibration periods. In the case of complex structural systems, a greater number of modes must be taken into account. In order to evaluate the contribution of each mode to the overall response, the concept of *effective modal mass* has been introduced.[4]-[7]

The elastic resistance of the system can be expressed in terms of normal coordinates

$$F_s = r y = r \Phi q \quad (14)$$

Since the inertial and restoring (resistance) forces are equivalent, equation (8) in normal coordinates takes the form

$$r \Phi = m \Phi \omega^2 q \quad (15)$$

Substituting (15) into (14), we get  $F_s = m \Phi \omega^2 q$ . The elastic resistance vector for the  $i$ -th mode  $f_{s,i} = \varphi_i \omega_i^2 q_i$ . Let  $q^*$  - be the solutions to the equation

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$$\ddot{q}_i^* + 2\xi_i \omega_i \dot{q}_i^* + \omega_i^2 q_i^* = \ddot{y}_0 \quad (16)$$

$$m_i^{eff} = \frac{L_i^2}{M_i m_{r106}} \quad (18)$$

$$f_{s,i} = m \varphi_i \frac{L_i}{M_i} \omega_i^2 q_i^* \quad (17)$$

The vector sum of elastic forces in the direction of the seismic excitation according to the  $i$ -th mode  $e^T f_{s,i} = e^T m \varphi_i \frac{L_i}{M_i} \omega_i^2 q_i^*$  or, given that  $e^T m \varphi_i = \varphi_i^T m e = L_i$ ,  $e^T f_{s,i} = \frac{L_i^2}{M_i} \omega_i^2 q_i^*$ , where the quantity  $\frac{L_i^2}{M_i}$  is called the effective modal mass and has the dimension of mass.

The sum of the effective modal masses is equal to the vector sum of the concentrated masses of the main system  $e^T m \varphi_i = \sum_{i=1}^N \frac{L_i^2}{M_i} = \sum_{i=1}^N \frac{(\varphi_i^T m e)^2}{\varphi_i^T m \varphi_i}$ , where  $N$  — the number of dynamic degrees of freedom (concentrated masses).

It is much more convenient to express the effective modal mass of the  $i$ -th mode as a fraction of the total mass

where the symbol is defined  $m_{r106} = e^T m e$ .

Many standards require that modes with  $m_i^{eff} > 0,05$  be taken into account, and the sum of the effective modal masses of the modes considered must be at least 0.85. SP 14 standards establish that the sum of the effective modal masses of the modes considered in the calculation must be at least 0.9 for horizontal vibrations and 0.75 for vertical vibrations. However, this requirement applies only to systems in the form of a cantilever beam with uniformly distributed mass. For complex structural configurations, maximum stresses may be determined by higher modes with a small effective modal mass.

*Example 2.* Let the base of the system from Example 1 oscillate with an acceleration of  $\ddot{y}_0 = 100 \exp(-2t) \sin(11t)$ , directed at a  $30^\circ$  angle to the horizon (Fig. 3). The direction cosine vector for three degrees of freedom  $e^T = \{0,866 \ 0,5 \ 0\}$ . [1]

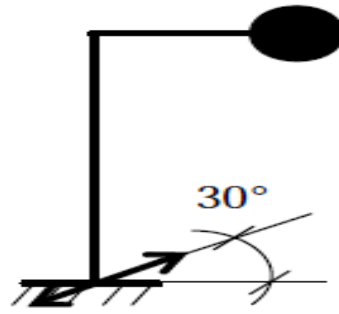


Fig. 3. Design system

Since the eigenvectors are orthonormal with respect to the mass matrix  $\Phi^T m \Phi = E$ , The modal masses for all modes of vibration are equal to one.

We will assume that the modal damping coefficient is the same for all modes.  $\xi = 0,05$   
 $C_1 = 2 \cdot 0,05 \cdot 11,1 = 1,11$ ;  $C_2 = 1,92$ ;  $C_3 = 2,33$ .

In this case, the modal stiffnesses are equal to the natural frequencies  $R_1 = 123$ ;  $C_2 = 369$ ;  $C_3 = 544$ .  
 Seismic load factors

$$\frac{L_1}{M_1} = \frac{(-0,01927 \cdot 0,866 \cdot 200 + 0,05457 \cdot 0,5 \cdot 200 + 0)}{1} = 2,119$$

$$\frac{L_2}{M_2} = \frac{(0,06749 \cdot 0,866 \cdot 200 + 0,02067 \cdot 0,5 \cdot 200 + 0)}{1} = 13,756$$

$$\frac{L_3}{M_3} = \frac{(-0,00859 \cdot 0,866 \cdot 200 + 0,03994 \cdot 0,5 \cdot 200 + 0)}{1} = 2,506$$

Total effective mass:  $200 \cdot 0,866^2 + 200 \cdot 0,5^2 = 200$ ; effective modal masses for the three shapes:  $M_1^{eff} = \frac{2,119^2}{200} = 0,0225$ ;  $M_2^{eff} = 0,9461$ ;  $M_3^{eff} = 0,03147$ .

As a result of the transformations, three independent equations were obtained:

$$\begin{aligned} \ddot{q}_1 + 1,11 \dot{q}_1 + 123q_1 &= 2,12\ddot{y}_0, \quad \ddot{q}_2 + \\ 1,92 \dot{q}_2 + 369q_2 &= 13,76\ddot{y}_0, \\ \ddot{q}_3 + 2,33 \dot{q}_3 + 544q_3 &= 2,51\ddot{y}_0 \end{aligned}$$

The solution in standard coordinates is shown in Fig. 4.

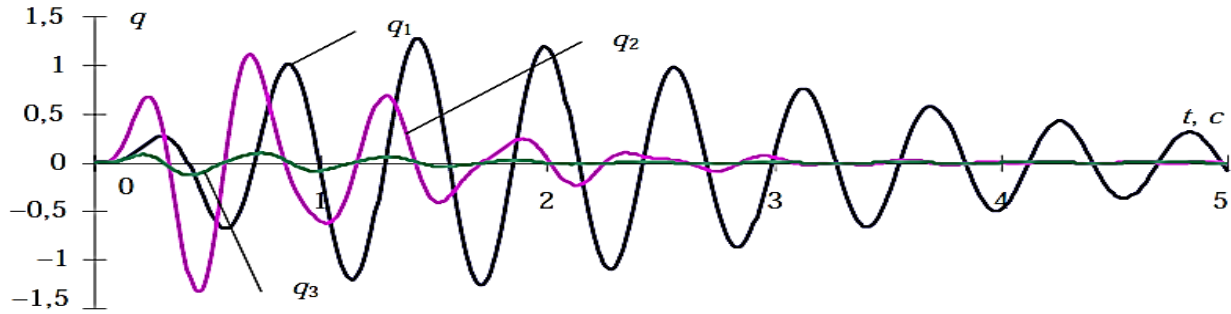


Fig. 4. Normal coordinates

Fig. 5 shows the variation of the elastic resistance over time, taking into account the three modes of vibration. Table 1 lists the contribution of each mode to the elastic reaction. The value  $M_{max}$

represents the maximum bending moment in the support section of the column.

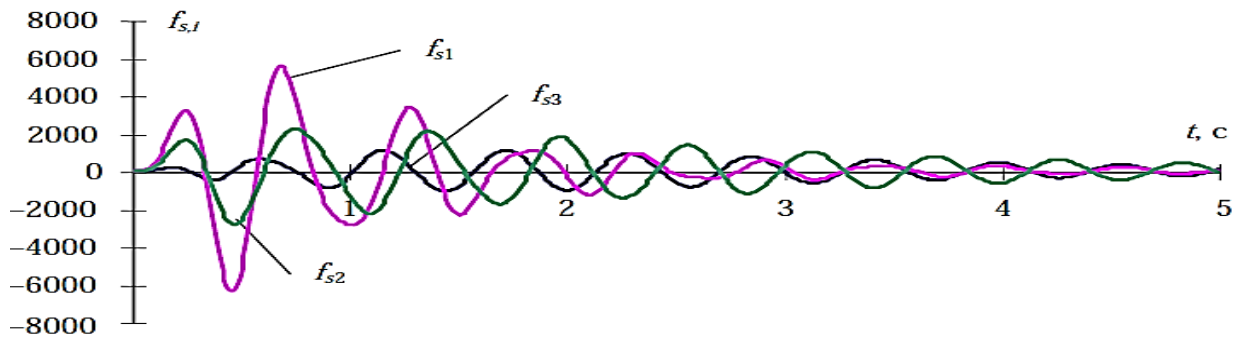


Fig. 5. Change in elastic resistance over time

Table 1. Types of oscillations

Types	1	2	3
$f_{s1}$	-0,015	1,032	-0,017
$f_{s2}$	0,149	0,697	0,154
$f_{s3}$	0,996	-0,047	0,051
$M_{max}$	0,266	0,731	0,002

An analysis of Table 1 shows that, despite its small modal mass, the first mode makes a significant contribution to the elastic responses. This is because the first mode is a torsional mode. European standards require that all modes with  $T_i > 0,2$  s be taken into account if the first or second modes are torsional. A distinction should be made between torsional modes

of vibration and dynamic degrees of freedom associated with mass rotation. The contribution of each mode to different types of responses varies significantly, although the correlation with the effective modal mass remains.

**References:**

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## EFFECT OF WATER-CHEMICAL PARAMETERS OF SHIP ENGINE COOLING SYSTEMS ON ENGINE RELIABILITY

**Abstract:** To ensure normal operation of an internal combustion engine, it is necessary to select a cooling system that maintains optimal temperatures in the combustion chamber, cylinder head, cylinder walls, and piston surfaces at levels close to their maximum permissible values.

The coolant parameters characterize the physicochemical and thermophysical properties of the heat-transfer medium within the cooling system. Reliable engine operation can be ensured if the cooling agent meets the following requirements: it must not cause surface corrosion and must remain stable over an extended period. These properties can be achieved through the appropriate chemical composition of the heat transfer medium and special treatment.

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The article considers the influence of water-chemical parameters in a marine engine cooling system on the reliability of engine operation when various chemical additives are used.

**Key words:** hydrogen value; water hardness; cooling system; corrosion wear; gravimetric study; protective effect; viscosity.

**Language:** English

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### Introduction

The water-chemical parameters of the coolant characterize the physicochemical and thermophysical properties of the heat carrier in the cooling system. Reliable engine operation can be ensured if the coolant meets the following requirements [1]:

- It does not cause corrosion of the metals from which the parts and assemblies of the engine cooling system are made;
- It does not tend to form sediment deposits on surfaces;
- It maintains stability over a long period of time, in particular, it has a low foaming index;
- It is characterized by chemical stability and does not enter into chemical reactions with the non-metallic parts of the engine cooling system, rubber hoses, and joints with which it is in constant contact.

### Materials and Discussion

Ensuring the listed properties could be achieved through the appropriate chemical composition and special treatment of the heat carrier. The main characteristic of the heat transfer agent's corrosive aggressiveness is the pH of the hydrogen index. As a rule, the corrosion intensity of ferrous metals increases significantly in an acidic environment, that is, in conditions where the hydrogen index of the coolant is low. The seasonal variation of the hydrogen index pH (maximum in summer, minimum in winter) depends on temperature changes and the intensity of photosynthesis. In practice, pH depends on the components dissolved in water, primarily carbon dioxide. Through research, we established that instantaneous changes in the corrosion of steel engine parts occur when the coolant hydrogen index equals 9.5 [2]. It should also be noted that changes in the heat-carrier pH promote the solubility of the iron oxide layer, and the rate may increase at high cooling-agent temperatures when  $\text{pH} < 9.2$ .

In addition to steel, the hydrogen index actively affects aluminum alloys. As pH increases, the corrosive degradation of these alloys intensifies. Therefore, this characteristic must be taken into account when preparing coolant for engines whose cooling systems predominantly contain aluminum parts.

A particularly significant influence on the formation of sediment deposits on surfaces is exerted

by the content of various types of salts in the heat carrier, which is characterized by the hardness index. The majority of dissolved salts in natural water are sodium, calcium, and magnesium salts (up to 94%). Water hardness, which affects the rate of sediment layer formation on surfaces, is determined by the number of dissolved salts, and for diesel engines, the hardness should not exceed 1.5–3 mg/l.

Cavitation-corrosive degradation and the formation of sediment layers on surfaces are among the main factors affecting the reliability and efficiency of marine engine cooling systems, and 40% of equipment failures are caused by surface corrosion. During engine operation, if the coolant does not undergo special treatment, the following negative phenomena may occur:

- Erosive-corrosive damage to the surfaces of the cylinder block and the cylinders themselves.
- Manifestation of stress concentration within the cylinder volume;
- The formation of sediment layers in the cooling jacket space and the system's heat exchangers leads to changes in the engine's temperature regime, increased wear of the cylinder face, and excessive fuel consumption.

In modern engines boosted for crankshaft rotation speed, the problem of corrosive degradation is further exacerbated by cavitation erosion caused by high-frequency vibration of the cylinder liner. Even more significant is the formation of sediment layers in the cooling system, such as sulfate, carbonate, sulfite, and phosphate salts [3]. The negative impact of these salts on the cooling system and engine operation increases service time and repair costs, and vehicle downtime grows.

The elimination of the aforementioned negative processes can be achieved through various coolant preparation methods, the purpose of which is to ensure the required hydrogen pH and to soften the liquid. In the case of marine engines, this goal can be achieved by adding special compounds to the coolant that alter the physicochemical properties of the heat carrier. At the present stage, two classes and three main types of compounds are used in ship cooling systems, which are added to the cooling water:

- Oil-derived additives manufactured on a petroleum basis (di-oxidant);

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- Chemical additives representing a mixture of inhibitors;

- Complex additives consisting of corrosion inhibitors and organic additives, which in turn reduce the intensity of corrosion and cavitation erosion.

Chemical additives increase the passivity of metals by forming a protective layer on their surface, as they neutralize substances that cause scale deposits and raise the pH level. Chromate-based additives are particularly noted for their inhibiting properties; however, they are toxic and require special precautions during use. Reducing the concentration of additives leads to the breakdown of individual surface areas in the form of so-called pitting corrosion.

Unlike chromium-based additives, boron nitrate-based additives are non-toxic. Such additives are considerably less toxic, and increasing or decreasing their concentration does not affect the corrosion rate.

Water-emulsion type additives are anti-corrosion oils that form a white emulsion when dissolved in water. When this emulsion is used, the surfaces to be cooled are coated with an oil film that inhibits corrosive deterioration and the formation of scale deposits. In addition, the oil film reduces cavitation damage. The drawback of this type of additive is the risk of local overheating, as increasing the oil film thickness worsens the heat exchange process. Oil-based additives can form a layer 0.3–0.5 mm thick during 500–1000 hours of diesel engine operation. Beneath this layer, when the temperature exceeds 170°C, destructive processes may develop on metal surfaces, which is why the use of this type of additive in high-performance engines is not recommended [4].

In cooling systems that use low-freezing-point liquids based on ethylene glycol, the recommended anti-corrosion additive is disodium phosphate ( $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$ ), which protects cast iron, steel, and copper components from corrosion, as such antifreeze solutions are characterized by a weakly acidic reaction.

It should be noted that a general classification of additives used in engine cooling system coolants does not currently exist, which complicates their analysis. Therefore, in addition to chemical composition, the following criteria should be added to the classification of additives:

1) The area of application - indicates whether the additive is added to water or to a mixture of water and ethylene glycol;

2) By purpose - universal and non-universal. The former is intended for all types and levels of forcing of diesel engines;

3) The range of effects on processes in the cooling system - complex (reduces corrosion, cavitation erosion) and non-complex;

4) By physicochemical composition of components - organic, inorganic, and mixed;

5) By the mechanism of action on the protective surface - anodic, cathodic, and mixed;

6) By the number of components - single-component and multi-component.

Since cavitation erosion is the main factor in the destruction of engine components, it is necessary to use the coolant additives that counteract this process by modifying the properties of the heat transfer fluid. It is known that reducing the effects of the cavitation process requires increasing the following parameters: density, viscosity, surface tension, saturated vapor pressure, temperature, and static pressure.

Research has revealed that the density of a liquid increases with the addition of any type of dissolved substances to the cooling water, particularly high-molecular-weight polymers. The presence of polymers in the coolant alters its rheological properties, which reduces hydraulic resistance. This, in turn, reduces the rate of growth of cavitation damage and the intensity of sediment layer formation [5, 6, 7]. Polymers of this type include polyacrylamide and sodium carboxymethylcellulose.

To reduce surface tension, surface-active substances are used, which also alter the dynamics of cavitation damage formation and growth [8, 9]. The addition of surface-active compounds to the coolant ensures:

- Reduction of surface tension at the interface between gas and liquid layers;

- Limitation of sediment layer formation;

- Intensification of mass and heat exchange processes in the boiling and condensation zones (phase transition);

- Formation of a protective layer on the surface and reduction of the intensity of erosive and corrosive processes.

It should be noted that corrosion is a significant factor in the destruction of cooling system components. Therefore, it is essential to include corrosion inhibitors in the additive composition. Since ferrous metals are used as the primary material for components in both medium and high RPM diesel engines, particular attention should be paid to components that mitigate corrosion. One such component is the increase of the pH value, which simultaneously leads to a reduction in polymer degradation and an increase in detergent properties. For example, for cast iron parts, sodium silicate can be used as an additive, where a concentration of 0.1–0.3% ensures a solution pH value of 9–10 [10].

Of particular importance is the protection of the cylinder block, which is made of aluminum alloys. An effective inhibitor for its protection is the addition of nitrates and sodium tripolyphosphate to the additives, as they possess high protective properties for aluminum alloys [11]. It should be noted that in

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additives for vibroacoustically active engines with cylinder blocks made of aluminum alloys, additives intended for steel, cast iron, and copper alloys should also be included.

To enhance the anti-corrosion effectiveness of additives, the following can be added: sodium silicate for the protection of steel, and disodium phosphate for the protection of steel, cast iron, and copper. It should be noted that increasing the number of components in additives raises their cost, complicates manufacturing, and increases the toxicity of the coolant. Therefore, the present study aimed to evaluate the effectiveness of multifunctional additives with a minimum number of components and low concentrations.

To determine the properties of individual components and various compositions, two methods were used: gravimetric and potentiostatic. The gravimetric method is one of the simplest and most effective methods for assessing corrosion. When using the gravimetric method, the rate of the corrosion process and, accordingly, the anti-corrosion properties of the additives are evaluated based on changes in metal samples immersed in the solution under study. The disadvantage of the method is the need for an

extended testing period to obtain results and a large number of test metal samples.

The present study was conducted using base fluids with and without additives. As is known, metal corrosion depends on factors such as fluid temperature, metal surface condition, fluid movement, contact with other metals, contact area, and others. The samples were taken in the form of plates measuring 50x25 mm and 5 mm in thickness, from the metals present in the cooling system. All plates were electrically isolated from one another and were fully immersed in the fluid for 90 days.

The gravimetric study was carried out in cooling water for two different additive compositions:

A - containing sodium nitrate, sodium phosphate, sodium molybdate, and benzotriazole at defined concentrations;

B - containing sodium silicate, ammonium molybdate, and syntanol at defined concentrations.

The physicochemical properties of the fluids under study are presented in Table 1.

After the tests were conducted, the metal samples were washed with distilled water, dried to constant mass, and weighed on an analytical balance. The results of the study are presented in Table 2.

**Table 1. Physicochemical Properties of the Coolants Under Study**

Physicochemical characteristics	Water without an additive	Solution A	Solution B
Boiling temperature, °C	100 ±0,5	101 ±0,5	101 ±0,5
Freezing temperature, °C	0 ±0,5	-1 ±0,5	-1 ±0,5
Hydrogen value, pH	7,6	11,3	11,4
Viscosity	0,985	1,015	0,987
Surface tension, n/m <sup>2</sup>	72	36	38

**Table 2. Mass Losses of Samples in the Fluids Under Study ΔG, g**

Material	Water without an additive	Solution A	Solution B
Steel ST20	-0,334	-0,002	-0,003
Cast iron CI24	-0,826	-0,068	-0,073
Aluminum compound, Al9	-0,010	-0,005	-0,002
Brass	-0,016	-0,004	-0,004
Copper	-0,005	-0,002	-0,002

The metal corrosion wear rate  $\Delta G_c$ , the wear coefficient  $Z$ , and the protection effect  $r$  during the experiment were determined by the following formulas:

$$\Delta Gb = \frac{(G_1 - G_2) \cdot 10^6}{365 \cdot (2 \cdot (DB + BH + Hd))}, \quad (1)$$

where: H x B – plate dimensions; D – plate thickness;  $G_1$  – sample mass before testing;  $G_2$  – sample mass after testing.

Wear coefficient

$$Z = \frac{1 - \Delta G_1}{\Delta G_s} \cdot 100\%, \quad (2)$$

where  $\Delta Gb$  – sample mass losses in the base fluid;  $\Delta G_s$  – sample mass losses in the solution.

Protection effect

$$r = \frac{\Delta Gb}{\Delta G_s} \quad (3)$$

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**Table 3. Corrosion Process Intensity in Various Solutions, t = 20 °C**

Material/Solution	Water without an additive	Solution A			Solution B		
	$\Delta G \cdot 10^{-2}$	$\Delta G \cdot 10^{-2}$	Z, %	r	$\Delta G \cdot 10^{-2}$	Z, %	r
Steel ST20	0,121	0,0077	93,4	174	0,0021	99,2	114,8
Cast iron CI24	0,305	0,024	92,7	12,7	0,0257	92,0	11,9
Aluminum compound, Al9	0,035	0,018	50,0	1,93	0,0071	80,0	6,0
Brass	0,057	0,014	75,0	3,93	0,0144	75,0	3,93
Copper	0,002	0,007	40,0	2,45	0,007	40,0	2,45

Based on the results of the gravimetric study, the following conclusions can be drawn:

- The use of the aforementioned additives in the “Tobol” engine coolant makes it less corrosively active compared to water containing no additives.

- The additives in water exert a fairly effective anti-corrosion effect against the corrosive destruction of both ferrous and non-ferrous metals.

A comparison of the corrosion protection coefficients of parts involved in the cooling system for solution A and solution B allows the following conclusion to be drawn: the use of solution A in the cooling system is advisable when the parts are primarily made of cast iron and steel, as it is a more effective means of protecting these surfaces than solution B. In turn, the use of solution B is considerably more advisable for surfaces made of brass and aluminum alloys, meaning its use is more effective when parts made of non-ferrous metals predominate in the cooling system.

In all conducted studies, it was noted that when additives are used, the increase in the corrosion protection effect is associated with an increase in fluid

temperature. This is an important factor and provides a guarantee that the protective properties of the additives will be maintained in the context of high-temperature cooling systems in the future.

### Conclusion

The water-chemical regime, determined by the properties of the heat transfer medium, significantly influences the reliable operation and optimal thermal conditions of a marine engine cooling system. To ensure the required properties of the heat transfer medium, a particularly effective method is to add multifunctional complex chemical additives at low concentrations. Their quantity must be determined at 0.5–1.0% of the mass of the coolant present in the internal circuit.

During the research, it was noted that when additives are used, the enhancement of the anti-corrosion protective effect is associated with an increase in fluid temperature, which is an important factor in maintaining the protective properties of the additives in high-temperature cooling systems.

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