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CONTENT

AGRICULTURAL SCIENCES

Rutta O.

CLUSTERING AS A PROMISING FORM OF ORGANIC
AGRICULTURAL PRODUCTION IN UKRAINE.....4

CHEMICAL SCIENCES

Klimko Yu., Koshchii I.

SYNTHESIS AND PHARMACOLOGICAL PROPERTIES OF
1-[(ADAMANTAN-1-YL)-4-PHENYL]-3(4)-
PYRAZOLYLUREA AND THIOUREA 12

**Nabiyeva M., Efendi A., Ahmadzade M.,
Nabiyev F.**

STUDY OF GENETIC PARAMETERS OF THE
ESTERIFICATION REACTION 20

EARTH SCIENCES

Isgandarov E., Zeynalov I.

STRUCTURE OF MESOZOIC DEPOSITS IN THE SAATLY-
SABIRABAD AREA BASED ON GRAVITY SURVEYING IN
COMBINATION WITH SEISMIC SURVEYING.....23

ECONOMIC SCIENCES

Rakviashvili A.

MARKETING STRATEGIES AS A TOOL FOR MANAGING
ENTERPRISE COMPETITIVENESS.....29

Uvalieva A., Kobilov A.

INTERACTION OF TRANSPORT MODES IN TRANSPORT
HUBS AND THE ROLE OF MULTIMODAL LOGISTICS
CENTERS 33

Uvalieva A., Kobilov A.

IMPROVING THE INTERACTION OF TRANSPORT
MODES IN THE AKTAU HUB ON THE BASIS OF A
MULTIMODAL LOGISTICS CENTER 38

Darchia I.

USING OUTSOURCING TECHNOLOGY TO MANAGE
ENTERPRISE BUSINESS PROCESSES 43

Karimov K., Jafarova N., Safarli Z.

ENHANCING ENERGY EFFICIENCY IN THE CONTEXT OF
INNOVATIVE MODERNIZATION OF THE AZERBAIJANI
ECONOMY 50

Karimov K., Shahveranova E.

DIGITALIZATION OF THE OIL INDUSTRY: SCIENTIFIC
ASPECTS AND JUSTIFICATION OF INTELLIGENT
TECHNOLOGIES 58

Mehdiyev Kh., Kerimova M., Abbasov Yu.

COMPARATIVE ANALYSIS OF THE EFFECTIVENESS OF
INTERNAL AND EXTERNAL FINANCIAL CONTROL IN A
MARKET ECONOMY ENVIRONMENT 66

JURISPRUDENCE

Abdulloeva D.

THE ROLE OF LOCAL GOVERNMENT IN ENSURING
DEMOCRATIC GOVERNANCE: A CONSTITUTIONAL
AND LEGAL ANALYSIS.....73

MATHEMATICAL SCIENCES

Asgarli R., Abbasova A.

MATHEMATICAL MODELING ONE PROBLEMS FROM
ECOLOGY 77

Milyute E., Milyus A.

SPATIAL MODES AND HELICAL STRUCTURE OF
SWIRLING FLOW IN A CYLINDRICAL RESERVOIR WITH
A STATIONARY CENTRAL ROD 83

MEDICAL SCIENCES

Shkiryak A., Khanenko S.

THE ASSOCIATION BETWEEN VITAMIN D DEFICIENCY
AND COMMUNITY-ACQUIRED PNEUMONIA 98

Shkiryak A., Khanenko S.

VITAMIN D AND PREVENTION OF VIRAL
INFECTIONS 103

Usenko K.

DYNAMICS OF ANGIOTENSIN-CONVERTING ENZYME-
2 EXPRESSION IN THE RETINA IN EXPERIMENTAL
DIABETIC RETINOPATHY AND ITS MODIFICATION BY
INSULIN 113

Sutbayeva N., Spabek A., Kanatkyzy G.,

Kartbayeva A., Khabiyeva M., Kuantaykyzy A.

INTERSTITIAL LUNG DISEASES: A RETROSPECTIVE
CASE SERIES ANALYSIS IN A SPECIALIZED CENTER ..116

PEDAGOGICAL SCIENCES

Azadaliyeva Sh.

THE ROLE AND IMPORTANCE OF SELF-EDUCATION IN
THE FORMATION OF PERSONALITY..... 123

Sapakova A., Kanatkyzy Sh.

PEDAGOGICAL FOUNDATIONS OF USING ARTIFICIAL
INTELLIGENCE TECHNOLOGIES IN THE PROCESS OF
CHEMISTRY EDUCATION 126

PHARMACEUTICS

Raghad Abdulsalam Khaleel, Saba Talib

MELATONIN USAGE AMONG MEDICAL STUDENTS IN
AL-IRAQIA UNIVERSITY: A SUBJECT REVIEW 131

PHILOLOGICAL SCIENCES

**Tulekova G., Kyrgyzbay B., Nurmanova Zh.,
Parmanov B.**

PRAGMATIC ADAPTATION WHEN TRANSLATING
CARTOON/FILM TITLES 140

PHYSICAL SCIENCES

Abou Zeid A., Elbadrawy Z., Abdelhadi R.

FUNCTIONALIZATION OF CALIX[4]ARENE WITH
DIGLYCOLAMIDE-PYRIDINE LIGAND FOR SELECTIVE
RECOVERY OF RARE EARTH ELEMENTS FROM
AQUEOUS SYSTEMS 144

POLITICAL SCIENCES

Syzdykova A., Slyambayeva D., Baizova L.

THE FORMATION OF POLITICAL SCIENCE: HISTORICAL
DEVELOPMENT AND PHILOSOPHICAL FOUNDATIONS
OF THE DISCIPLINE (BASED ON THE REFORMS OF THE
TANG DYNASTY) 155

PSYCHOLOGICAL SCIENCES

Saypak H., Efilti E.

INVESTIGATION OF VULNERABLE NARCISSISM LEVELS
OF UNIVERSITY STUDENTS ACCORDING TO
DEMOGRAPHIC VARIABLES 162

SOCIAL SCIENCES

Dr Hossain K., Khandakar A., Khandakar A.

EFFECTIVE LEADERSHIP PRACTICE IN 21ST CENTURY
TO EVALUATE THE KEY TRAITS OF SUCCESSFUL
LEADERS AS GLOBAL PERSPECTIVE 169

TECHNICAL SCIENCES

Kassymkhan N.

FACTORS AFFECTING THE DURABILITY OF
REINFORCED CONCRETE BRIDGE STRUCTURES 207

Ustinovich V.

NEURAL ENGINES FOR SELF-OPTIMIZING CODE:
RESEARCH AND ARCHITECTURE BEHIND THE
APPROACH 213

Ovcharuk V.

SOLVING TRANSPORTATION PROBLEMS USING
LINEAR PROGRAMMING IN MATHCAD 218

AGRICULTURAL SCIENCES

CLUSTERING AS A PROMISING FORM OF ORGANIC AGRICULTURAL PRODUCTION IN UKRAINE

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Abstract

This article analyses the state of organic agricultural production, using the development and operation of agricultural clusters as an example.

The aim of the study is to summarise the experience of clustering in the agro-industrial sector and to analyse the structure of the agricultural cluster for organic vegetable production. Among the tasks set to achieve this aim were: summarising global experience of the cluster approach in the management of economic activity, particularly in the agricultural sector; examining the history of the clustering process and the prospects for the development of agricultural clusters in Ukraine (using the Southern region as an example), and analysing the structure of the agricultural cluster for the production of organic vegetable products.

Enhancing the competitiveness of the vegetable sector in Southern Ukraine and the region itself is relevant in the context of creating regional agricultural clusters for the production of organic vegetable products, which combine scientific, educational, logistical and marketing functions with the involvement of consulting, financial and certification bodies.

The operation of regional agricultural clusters, including organic ones, will help ensure that the consumer market is well-supplied with vegetable produce, particularly organic produce, meet consumer demand for high-quality and safe vegetable produce, and strengthen the region's export sector. Furthermore, the operation of the agricultural cluster will help to meet the interests—including social, economic and environmental ones—of all market participants.

Agricultural clusters represent one of the most promising forms of collaboration between the state and the agribusiness sector, where specialisation and the concentration of production, the incorporation of innovative research from scientific institutions, and the establishment of closed production cycles ensure increased competitiveness and profitability of products.

The article examines the experience of European Union countries in supporting regional clusters and the potential for applying this experience to the development of individual regions and the strengthening of business positions.

Keywords: cluster, agro-industrial complex, innovation infrastructure, network structure, partnership, innovation agrocluster, sustainable development, competitiveness of the region.

Introduction Globalisation, internationalisation and integration are the processes that characterise the modern global economy. At the same time, integration at the level of individual countries and regions takes place through the formation of economic entities based on cluster models. Such models make it possible to avoid or minimise risks, particularly when introducing innovative technologies. These include sustainable technologies in agriculture, particularly organic ones. This enables the mobilisation of financial resources from all stakeholders, which also provides certain advantages for agricultural producers. In general terms, the cluster model combines production, infrastructure, science, education and other components of the product creation and production process (marketing, logistics, conformity assessment). Such integration makes it possible to bring together and motivate all participants in the innovation process to achieve the planned result, particularly provided there is adequate funding.

This funding model can be used by agricultural holding companies that bring together companies,

enterprises and organisations within a specific territory engaged in the production of a particular end product. The region where such clusters are located must be a hub for various types of resources, including socio-economic, scientific, innovative and human resources. Only with these resources in place will the clusters become sustainable and competitive entities [1].

In the final pre-war years in Ukraine, political and economic factors significantly hampered economic development and had a negative impact on the competitiveness of domestic enterprises and their products. Consequently, this hindered the expansion of the domestic consumer market and slowed the strengthening of export positions. Under these conditions, most regions of the country faced certain difficulties, which were due to insufficient provision and support for the socio-economic development of the territory, as well as the lack of strategic investment projects. At the same time, this stimulated the search for, development and implementation of new approaches to regional development.

Ukraine's integration into the European economic area and new approaches to regional development management call for the application of effective and innovative methods. The experience of European countries, where the cluster approach is widely used, shows that the functioning of clusters is an effective tool for enhancing a region's competitiveness and taking its economic development to a new level. Therefore, the use of the cluster approach in Ukraine today can be regarded as one of the priority and promising directions for the development of the economic sector.

According to the Ukrainian Ministry of Statistics, agriculture is currently the most resilient sector of the economy. Furthermore, as a source of raw materials for the processing and food industries, agriculture underpins the country's food security and quality of life [2, p. 14].

Therefore, efforts to enhance the competitiveness of individual regions, particularly in southern Ukraine, are being pursued in both the short and long term through the creation of regional agricultural clusters.

Prior to the war, the Kherson region ranked first among Ukraine's regions, including those in the south, in terms of vegetable production and accounted for a significant share of exports. Up to 90 per cent of vegetable production is grown by small-scale farms. Furthermore, the Kherson region is a leader in Ukraine in the production of organic vegetables using organic farming techniques [3, p. 14; 4, p. 691; 5].

Despite significant achievements in the field of organic farming, it should be noted that the process of managing individual stages of the business is of vital importance for the development of the domestic market for organic products and the export segment of organic products; this process must include market research, production itself, verification of compliance with national and international standards, logistics and product placement on the market, as well as the development of proposals for the implementation of all stages of the product life cycle.

The aim of the study is to summarise the experience of clustering in the agro-industrial sector and to analyse the structure of the agricultural cluster for organic vegetable production.

Materials and Methods The relevance of this area of research stems from the objective circumstances that have emerged in Ukraine's economy in recent years. The current state of the agricultural sector and the growth in agricultural exports are accompanied by the intensive use of agrochemicals in the production of conventional agricultural products and environmental pollution. At the same time, this is accompanied by a rise in public environmental awareness. Despite the presence of both external and domestic demand, the market for agricultural produce, including organic produce, in Ukraine is still developing rather slowly. The number of market operators working in this segment is unable to meet the growing needs of consumers. Most of the produce grown by households according to organic production principles does not reach consumers due to the inadequacy of the relevant infrastructure and mechanisms for the effective functioning of this market segment.

The processes of European integration currently underway in Ukraine are prompting a closer examination of the experience of effectively supporting and implementing the principles of the cluster approach in EU countries, in line with the EU's Common Policy on the Development of Regional Clusters. All EU countries are implementing the decisions of the Lisbon Summit (2000) regarding the implementation of programmes for the development of regional innovation systems based on the cluster model of production.

The subject of this study is modern management methods in agriculture, based on the creation of clusters, taking into account the priority areas for the sector's development in the southern region. The article examines methods for identifying potential clusters and their participants, assessing the effectiveness of their activities, as well as involving public authorities responsible for regional development, representatives of business, science, education and other regional and national institutions in addressing the relevant challenges. It examines innovative projects and programmes to support agricultural clusters, including those engaged in the production of organic products, which have been or are being implemented in leading countries worldwide, the European Union and Ukraine.

Results and Discussion. The increase in the competitiveness of certain regions by the leading countries of the world due to the implementation of the cluster concept is explained by the processes of globalization, the development of means of communication, and the active formation of network structures in national economies. A cluster association is considered to be a network of enterprises and organisations that are geographically interconnected by certain production relations. Such a network may include suppliers, including service providers, producers and consumers, research and education institutions, marketing and logistics companies.

It should be noted that agricultural clusters have a number of advantages compared to other forms of integration and contribute to the development of the industry through:

- 1) increasing the productivity of enterprises due to better access to the workforce and suppliers, specialized information, institutions and the expansion of sales markets;
- 2) stimulation of innovations through cooperation with scientific institutions and specialized educational institutions;
- 3) the possibility of implementing quick changes and sufficient flexibility, a lower price taking into account the pressure of competitors and the interests of all cluster participants;
- 4) minimization of risks that are distributed among cluster participants;
- 5) internal coordination of the actions of the cluster participants, which contributes to the efficiency of the use of external investments, the creation of enterprises thanks to a better understanding of the niche for new enterprises, the availability of the necessary raw materials, labor force. ;
- 6) infrastructure development in rural areas [6, p. 132; 7, p. 152].

Furthermore, among the key advantages of clusters over other corporate structures, experts note that clusters bring together enterprises that are not direct competitors but are able to supply one another with materials, resources, labour and technology to achieve high performance and objectives. These enterprises are geographically close to one another, meaning that the exchange of tangible and intangible resources does not require significant time expenditure. Such associations allow member companies to choose a specialisation and concentrate resources on a specific type of activity, which significantly reduces the overall time spent on the production cycle. As a rule, such structures find it easier to establish links with research institutes and educational establishments, which, in turn, will provide the cluster with the necessary qualified specialists [8, p. 28]. In addition, students at higher education institutions can familiarise themselves with the cluster's operations during the practical training, familiarization, production, etc.

However, along with these advantages and the improvement of the economic factors of the cluster concept, there are certain obstacles to the creation of real clusters. Among them:

- lack of awareness and awareness of business and individual branches of government about the advantages of cluster connections;
- imperfect partnership relations with local state administration bodies; weak connections between economic entities, scientific institutions and educational institutions;
- the imperfection of the legislation regarding the regulation of relations between partners, non-profit organizations, which regulates the cooperation of cluster subjects in the region.

The establishment and operation of agricultural clusters in Ukraine are seen as the foundation for the innovative development of Ukrainian agriculture, a way for the rural economy to emerge from the crisis by providing consumers with new (innovative) agricultural products, creating additional jobs, and developing infrastructure and social services in rural areas [7, p. 152].

The experience of the United States, Canada, Australia, Japan and European Union countries regarding the functioning of agricultural clusters confirms the effectiveness of a cluster strategy for the development of agriculture and rural areas. This is evidenced by the annual reports of the World Economic Forum. Among the 143 indicators, sub-indices and indices currently available across 117 countries, 13 indicators in the 'Internal Competition and Cluster Development' section characterise the state of economic clustering in each country [9].

The origin and emergence of clusters began more than fifty years ago. The criteria and prerequisites for regional development in different countries were the implementation of a policy of developing territories and their competitive economies through the creation of sustainable territorial associations.

In line with international practice, it is small and medium-sized enterprises that take the lead in establishing cluster associations. Furthermore, there are currently several models of cluster associations:

- Italian (the cluster consists of a large number of small companies that unite in various associations to increase their competitiveness);
- Japanese (at the core of the cluster is a leading company with a high volume of production, which integrates a large number of suppliers at various stages of the technological chain);
- Finnish (the cluster has a high level of internationalization of business and innovation);
- North American (competition between firms is most pronounced, most relationships are mediated by the market);
- Indo-Chinese (the main role is played by direct foreign investments, modern technologies that facilitate access to world markets);
- Soviet (market relations and competition are reduced to a minimum, production is concentrated in large companies).

Generally speaking, all the models listed can be categorised by origin: European, American and Japanese.

According to experts, the so-called Indochinese model of cluster development is the most widespread in Ukraine. This model posits that clusters develop through the involvement of large international companies via foreign direct investment, which enables the adoption of cutting-edge technologies and entry into global markets [10, p. 181; 11].

The process of economic clustering in Ukraine began in the late 1990s, and in the agricultural sector in 2008–2009. However, the formation of agri-clusters in Ukraine is hindered by a number of factors, including: the agribusiness sector's psychological reluctance to merge; low motivation among cluster participants to act collectively; the absence of a comprehensive legislative framework for clustering and mechanisms for implementing legal norms and regulations regarding regional initiatives; the inadequacy of state support and programmes for the development of cluster associations; a lack of skills and experience in effective partnership and an understanding of their necessity for the successful development of agribusiness. Domestic legislation and regulations on the principles of state agricultural policy do not provide for the regulation of agricultural clusters' activities or their support. At a time when supporting the development of clusters in the agricultural sector is a priority in the development strategies of many regions around the world [12].

It should be noted that the consolidation of enterprises and organizations into agricultural clusters will contribute to increased business activity among economic entities and help overcome the negative factors hindering the development of the Ukrainian economy. Coordinated actions and joint efforts by government agencies, scientific and educational organizations, and agribusiness representatives are the key to success, strengthening the economy's competitiveness, and raising the standard of living for the Ukrainian population amid fierce competition in international markets. The cluster's integration ties help agricultural and processing enterprises adapt to competitive conditions, which is extremely important for the development of the agricultural sector [13, p. 108].

The economic and social development strategies of most regions in Ukraine have opted for the creation of innovation clusters. Furthermore, the mechanisms for implementing these strategies include: public-private partnerships, cooperation, clustering, the promotion of entrepreneurial activity, and inter-regional cooperation. The implementation of these strategies involves the development and implementation of annual programmes and action plans, as well as the creation of appropriate mechanisms for cluster formation [14]. For example, in the Strategy for Economic and Social Development of the Kherson Region [15], among the main tasks for the development of agro-industrial production and the enhancement of its potential and efficiency, emphasis is placed on the creation of an agro-industrial research and production cluster based at the Regional Agro-Industrial Centre.

Ukraine's agribusiness is one of the key sectors of the national economy, contributing to its gross domestic product (GDP). Over the last 10 years, prior to the full-scale military invasion of Ukraine, record harvests were recorded, and in 2020, agribusiness accounted for 9% of the country's total GDP. Therefore, state support, particularly in terms of legislation and financial decisions, will facilitate and support the activities of agricultural producers [16; 17].

The growing environmental awareness and responsibility among business representatives has spurred the adoption of environmentally friendly technologies across various sectors of the economy, particularly in agriculture. The introduction of organic farming methods and organic technologies is one of the most important aspects of the food sector's development in any country. Consequently, local authorities in a number of regions are supporting agribusiness through their own budgetary resources to encourage the development of the organic sector.

Ukraine, which is currently among the ten European countries with the most dynamic growth in the organic market, has not remained on the sidelines. Over the past few years, a number of legislative acts have been adopted that recognise organic farming and production as a priority area for the development of the national economy [18].

It should be noted that the relevant agricultural sector in Ukraine is regulated by current legislation, which is still in the process of being developed and has an imperfect regulatory framework. Furthermore, unlike in many countries around the world, where organic producers receive support, particularly financial support, through national and regional programmes [19], domestic producers are still awaiting fundamental changes in this area.

Global practice confirms high competitiveness and stable economic growth due to factors that stimulate the introduction of new technologies and improvement of the innovation environment.

The modern food market is characterized by a growing demand for organic products. This situation is explained by the increase in environmental awareness of the population. At the same time, despite the growth in both domestic and external demand and the designation of agricultural production as a priority, the market for organic produce in Ukraine is still developing rather

slowly.

The current number of operators in this market segment is unable to meet consumer demand. At the same time, produce grown by private households in accordance with organic production principles does not reach consumers due to the lack of adequate infrastructure and effective mechanisms for the functioning of this market segment [20].

Leading European and global practices have shown that this problem can be solved by establishing regional agricultural clusters, including organic ones. Clusters will contribute to regional development and strengthen the position of businesses. After all, clusters are a driving force that has long been adopted in many countries as a model for regional competitiveness and its enhancement at both local and international levels.

Agricultural clusters represent one of the most promising forms of collaboration between the state and the agribusiness sector, where specialisation and the concentration of production, the incorporation of innovative research from scientific institutions, and the establishment of closed production cycles ensure increased competitiveness and profitability of products. At the state level, stable socio-economic development of the region is achieved through the development of rural areas into modern agricultural service, agro-industrial, residential and cultural zones. The organisation of clusters and their activities will contribute to increased employment, the rational use of natural resources, the development and strengthening of scientific potential, and so on [21].

Ukraine's integration into the global economic community requires new approaches in various spheres of public life and production, particularly in the agricultural sector.

Legislation, strategies and state programmes adopted in the years leading up to the large-scale military invasion of Ukraine are based on the formation, development and regulation of the most effective and promising areas for the implementation of the country's state scientific, technical and innovation policy. Among the most promising (particularly at the regional level) areas of the state's strategic development is the cluster approach to the implementation of innovation policy.

When analysing the agricultural market in the southern region, it is important to note that, alongside cereal crops, vegetable growing plays a significant role. A distinctive feature of the vegetable market is that fresh vegetables are used as raw materials for processing plants. Furthermore, the sector has specific characteristics, including a wide range of products sold; the rapid spoilage of vegetables in the absence of proper storage conditions; limited transportability; and various technological features of vegetable cultivation, including organic farming. A prerequisite for success in this market is clear specialisation across three main sectors: consumption of fresh produce, processing, and export. This will enable better satisfaction of market needs, both domestic and international.

The development of the consumer market for vegetable products must ensure that the interests of all market participants – from producers to exporters – are met, taking into account market saturation, the capacity of

processing enterprises, and the purchasing power of all sections of the population, whilst guaranteeing the quality and safety of vegetable products through the introduction of innovative technologies, including organic methods, the expansion of organic production, and the development of logistics.

In the final pre-war years in Ukraine, with production areas remaining virtually unchanged, the gross vegetable harvest increased by 50 per cent thanks to higher yields. This, together with the introduction of modern vegetable-growing technologies, contributed to improving the economic efficiency of the vegetable-growing sector through the implementation of a development strategy for vegetable-growing enterprises, which envisages the comprehensive development of sectors through the use of modern models, including clustering.

The organisation and operation of clusters for small and medium-sized businesses in the agricultural sector offer a number of advantages, including:

- reducing barriers to market entry through the standardisation of requirements within the cluster;
- achieving the benefits of organised staff training;
- efficiency in the procurement of technical equipment and IT software; gaining access to customers;
- transferring the cluster's positive reputation to its members (brand);
- the possibility of adapting regional vocational education systems (budget funding) to the needs of cluster enterprises;
- the implementation of regional innovation projects and programmes that take the cluster's interests into account.

Consequently, the development of the regional economy, alongside the growth of clustering, will help to boost employment and attract skilled professionals, whilst also fostering the development of related economic sectors and the service sector.

Regional economic development, through the creation and promotion of clusters, will encourage an increase in entrepreneurial initiatives and activity, and strengthen the joint efforts of all stakeholders: business, government representatives, academia, educators, and others. Furthermore, the activities of each party in the creation and development of clusters are complementary. Organising a cluster requires a high level of trust among participants, as well as long-term planning of the economic process. One way to develop clusters is through the implementation of regional economic and social programmes. To develop and implement such programmes, the interests of enterprises (including small and medium-sized ones), government bodies, consultancy, financial and research organisations, educational institutions and logistics companies are brought together. The application of a regional cluster approach in the agricultural sector will ensure the preservation of jobs for employees of small and medium-sized enterprises; contribute to the creation of new jobs; guarantee an increase in revenue for the local budget, etc.

Ukraine has significant potential for developing organic production on small-scale farms and meeting the domestic market's demand for organic products. One way for small-scale producers to assemble batches

of uniform produce and organise regular supplies of such produce to the domestic market is to establish clusters based on agricultural service cooperatives. Furthermore, given that organic production is typically carried out by small-scale producers, it is advisable to form such clusters on a regional basis. This makes it possible to expand and strengthen ties within the selected market segment; ensure a more secure market for product sales; increase access to financial resources; expand the information base; stimulate innovation and investment processes; improve production efficiency by reducing production and marketing costs; improve the quality of labour; expand opportunities to enter domestic and foreign markets; expand opportunities to obtain more qualified consultancy services; and improve the culture of entrepreneurship.

Organic farming cooperatives share certain characteristics with organic clusters, the main ones being the pooling of producers and their production resources, as well as the establishment of sales channels for finished products. At the same time, their differences lie in the presence of a well-developed market infrastructure, processing facilities and long-term storage facilities, as well as partnerships with product buyers and suppliers of resources and other inputs. As a rule, a cluster operates in closer cooperation with local authorities, local self-government bodies and civil society organisations. This enables cluster members to participate in state and regional support programmes, as well as international grant programmes providing technical assistance for the development of such sectors.

In recent years, cooperatives providing services in the field of organic agriculture have only just begun to emerge in Ukraine. They have become widespread in some regions, particularly in the south of Ukraine. With their further development, the transition to specialised organic clusters is justified and logical.

In the years leading up to the war, the organic produce market in Ukraine was growing rapidly and showed great promise for further development and increased participation by small-scale farms. Agricultural produce in Ukraine is produced by over 50,000 agricultural enterprises, 92% of which are small-scale farms [22].

Private farms produce around 50% of agricultural produce in Ukraine, the majority of which consists of fruit and vegetables. Furthermore, 30.8% of vegetable production is carried out by farms, whilst 46.1% is produced by various small and medium-sized family farms and private smallholdings [23]. The development and functioning of the vegetable market are closely linked to rising consumer expectations regarding product quality and increasing demand for organic produce.

A key factor in strengthening the role of the vegetable sector in the global food market is the specific geographical organisation of the infrastructure of economic entities. This infrastructure determines the nature, components and directions of the formation and functioning of the vegetable market as a complex system of relationships arising between enterprises and organisations performing functions of wholesale trade, transport, storage, various types of communication,

standardisation and certification, market monitoring, etc. Furthermore, this infrastructure must serve producers, contribute to ensuring the country's food security through effective relations between participants in the agricultural market regarding production volumes, and compliance with consumer requirements regarding product quality and safety. The development of infrastructure in individual regions stimulates the additional utilisation of their production capacities.

Improvements to the framework governing relations within such an infrastructure can be achieved through the creation of agro-industrial entities, which will facilitate the integration of raw material producers and processing enterprises. The main directions of this integration process are the convergence and gradual unification of these entities, and the development of relationships between them that are linked to the technological process and objectively aimed at pooling material resources in production and product sales. It is clustering that can create the conditions for enhancing the competitiveness of domestic vegetable products.

Based on the cluster model of organic production, marketing structures can be established to provide marketing support for cluster members, taking into account the infrastructure of the vegetable market. This approach enables small agricultural enterprises to avoid rising unpredictable costs and improve the efficiency of their operations.

At the same time, clustering enables vegetable producers not only to jointly promote their products, but also to establish an effective marketing support system for each participant

The efficiency of the entire vegetable market infrastructure will be improved through its integration into regional agricultural clusters, including organic ones, by:

- jointly modernising the material and technical aspects of vegetable cultivation;
- jointly determining production volumes and product ranges, establishing a common pricing policy, jointly developing marketing channels and building the cluster's brand;
- establishing an effective marketing infrastructure.

It is important that representatives of all levels of government (national, regional, local) participate in the creation of clusters, as they have a vested interest in the development of the territories and possess sufficient levers of influence (legal, financial, administrative) over the situation in the region. Public participation is vital in the process of forming regional clusters.

Furthermore, the cluster approach involves bringing together complementary enterprises, organisations and private farms linked by geographical and functional characteristics, including small-scale producers, agricultural enterprises, processing plants, service providers (manufacturers of fertilisers, including organic fertilisers, containers and packaging materials), financial and credit institutions, insurance companies, public authorities, educational and research institutions for joint activities within the region. Such a partnership provides an opportunity to jointly promote the produce

grown, thereby helping to satisfy the interests of each participant

The key features of a cluster are the direct links between its members, the effectiveness of which is based on two fundamental principles: the need to collaborate with others to establish efficient production of competitive products, and the existence of competition among partners, which encourages members to innovate. This is particularly relevant for the agricultural sector, specifically vegetable growing, as it is not among the most investment-attractive sectors and carries a number of risks.

However, the cluster model has a social dimension—it addresses the pressing challenges facing the development of rural areas. Consequently, a key strength of the cluster model lies in its systematic approach, unified management and cooperation between government bodies and the private sector, which enables the creation of a competitive agricultural sector and ensures the effective development of rural areas.

Another important factor in the development of cluster associations is the absence of interference from the government or big business in their formation. This promotes the competitiveness of economic entities operating within agri-clusters [24].

To solve the problem of the negative influence of big business and state policy on the development and functioning of domestic regional agricultural clusters, the experience of the countries of the European Union can be useful. This refers to the concept of the formation of the European technological platform developed and implemented in the EU, based on which the creation of an organizational and communication system of scientific and practical interaction of small and medium-sized business entities with innovative structures is envisaged. An example can be a number of technological platforms created in the EU: Advanced Engineering Materials and technologies (EuMAT), Advanced Construction Technology Platform (ECTP), European Nanoelectronics Initiative, Advisory Council (ENIAC), European Space Technology Platform (ESTP), European Steel Technology Platform (ESTEP), Future Manufacturing technologies (Manufacture), Hydrogen and Fuel Cell technology Platform (HFP), Nanotechnologies for Medical Applications (Nanomedicine) (Sumets, 2021). The practical implementation of the concept of European technological platforms demonstrates a systematic approach to the development of clusters: common goals, a strategy for achieving them, joint communications.

Even before the war began, Ukraine already had some experience of participating in these initiatives. The Ukrainian National Technical Platform 'Agrotechnical Platform' was established, bringing together a number of clusters in the agribusiness sector, namely: the 'Food Technologies and Industry' cluster, the 'Agri-Food Biotechnology', the 'Agroecology' cluster, the 'Food Safety and Quality' cluster, the 'Phytosanitary' cluster, the 'Veterinary Science', the 'Human Health' cluster, the 'Nanotechnology' cluster, the 'ICT' cluster, the 'Markets' cluster, the 'Socio-economic' cluster and the coordination cluster [25].

The full-scale military invasion of Ukraine and

military operations in regions where the agricultural sector had been developing most dynamically prior to the war drew the international community's attention to the issue of their recovery following the victory. Consequently, the agricultural sector was included in Ukraine's recovery plan, which was presented in Lugano in 2022. In addition, up to \$50 billion is planned to be allocated to the development of high value-added economic sectors, in particular agribusiness. Among the areas for the development of the agricultural sector, the plan also mentions facilitating the transition of the agri-food sector to 'green' growth.

Furthermore, farmers, as small and medium-sized enterprises, can actively participate in the national programme 'Ensuring Competitive Access to Capital', which concerns lending and other financial instruments for entrepreneurs.

Conclusions

Effective management of agricultural activities and the enhancement of the region's competitiveness are ensured through the establishment and operation of an agricultural cluster. The implementation of a cluster approach involves bringing together market participants within the region or the entire region into a cooperative structure with specific functional characteristics, the implementation of which encompasses the production of competitive vegetable products, the growth of cluster participants' financial results, the development of organic vegetable growing, the enhancement of investment attractiveness and the pace of development of logistics activities, and the development of the territory in which the cluster is located.

The operation of regional agricultural clusters, including organic ones, will help ensure that the consumer market is well-supplied with vegetable produce, particularly organic produce, meet consumer demand for high-quality and safe vegetable produce, and strengthen the region's export sector. Furthermore, the operation of the agricultural cluster will help to meet the interests-including social, economic and environmental ones—of all market participants. These include additional production capacity, job creation, expansion of the product range through organic production, guaranteed product quality and safety, improvement of the environmental situation in the region through the introduction of organic technologies, reduction of costs for organic certification, market research and logistics, promotion of products in domestic and foreign markets, and so on.

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CHEMICAL SCIENCES

SYNTHESIS AND PHARMACOLOGICAL PROPERTIES OF 1-[(ADAMANTAN-1-YL)-4-PHENYL]-3(4)-PYRAZOLYLUREA AND THIOUREA

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Abstract

A series of 1,3-disubstituted ureas and thioureas containing 1,3,5-trisubstituted pyrazole and (adamantan-1-yl)phenyl moieties were synthesized in 69–89% yields by reacting 1-(4-isocyanatophenyl)adamantane and 1-(4-isothiocyantophenyl)adamantane with 3- or 4-aminopyrazoles. The inhibitory activity of the obtained compounds against human soluble epoxide hydrolase (sEH) ranged from 15.2 to 51.2 nmol/L, and their solubility in water ranged from 44 to 83 μ mol/L.

Keywords: amines, 1,3-disubstituted ureas and thioureas, isocyanates and isothiocyantates, pyrazoles, adamantane derivatives, soluble epoxide hydrolase (sEH), inhibitors.

Introduction

Substituted pyrazoles exhibit a wide range of biological activities, including analgesic and anti-inflammatory [1], antibacterial [2], antifungal [3], antitumor [4], and antiviral [5] activities. They are also being studied as inhibitors of human soluble epoxide hydrolase (sEH) (IC₅₀ 220–224 nmol/L) [6]. Data on the inhibitory activity of pyrazole-containing compounds against p38 MAPK α protein kinase, as well as molecular docking results, have shown that the high activity of these compounds is due to the ability of the pyrazole pharmacophore site to bind up to two amino acid residues in the enzyme's active site [7]. 1,3-Disubstituted ureas containing a pyrazole group in their structure are being studied as inhibitors of the cyclin-dependent kinase CDK5 and glycogen synthase kinase GSK3 α/β [8], inhibitors of the BRAF sarcoma viral oncogene [9], inhibitors of the tyrosine kinase activity of the VEGFR-2 receptor [10], and selective dual inhibitors of mammalian targets of rapamycin complexes 1 and 2 (mTORC1 and mTORC2) [11]. Inhibition of JNK3 kinase by such structures is a promising strategy in the treatment of neurodegeneration [12]. A number of ureas containing a 1,5-diarylpyrazole group in their structure have been studied as dual inhibitors of cyclooxygenase-2 (COX-2) and sEH [13]. Human sEH is an enzyme involved in the metabolism of epoxy fatty acids (arachidonic acid metabolites) to the corresponding vicinal diols via the catalytic addition of a water molecule [14]. Inhibition of human sEH with target-directed inhibitors has beneficial effects on the treatment of hypertension and kidney diseases [15], as well as inflammatory and pain conditions [16].

Analysis of the sEH gene structure shows that it consists of two globular proteins, each containing its own C-terminal epoxide hydrolase and N-terminal phosphatase domains

for binding to different substrates [17].

Among the existing inhibitors of the C-terminal epoxide hydrolase domain, 1,3-disubstituted ureas occupy an important place. For example, small symmetrical ureas, such as 1,3-dicyclohexylurea, are potent inhibitors of sEH [18]. However, low aqueous solubility severely limits their use as dosage forms. To improve solubility, unsymmetrical ureas with a flexible side chain, such as 12-(1-adamantan-1-ylureido) dodecanoic acid (AUDA), were synthesized. Although this class of sEH inhibitors exhibits high activity in vivo, they are extremely rapidly metabolized, which reduces their applicability [19].

To date, more than 3,000 disubstituted ureas containing aliphatic, aromatic, and heterocyclic moieties have been studied as sEH inhibitors [20]. Many of the synthesized sEH inhibitors are adamantyl-containing ureas with a ureide pharmacophore center. However, compounds combining high activity, aqueous solubility, and metabolic stability have not been found among them.

Materials and Methods

IR spectra were recorded on a Bruker Alpha spectrometer using KBr pellets. ¹H and ¹³C NMR spectra were recorded on a Bruker AM300 spectrometer (300 and 75 MHz, respectively) in DMSO-d₆ and CDCl₃ at 25°C, using TMS as an internal standard. ¹³C NMR signal assignments were based on published data [25, 27]. Mass spectra were recorded on a Finnigan MAT Inco 50 instrument with direct sample injection in IE mode (70 eV). Melting points were determined on a Boetius melting stage (heating rate 4°C/min). Elemental analysis was performed on a PerkinElmer 2400 Series II instrument. The reaction progress and purity of the obtained compounds were monitored by TLC on Merck Silicagel 60 F254 plates, eluent MeCN–CHCl₃, 1:5.

The starting materials 1-(isocyanatophenyl)adamantane and 1-(isothiocyantophenyl)adamantane (2)

[23] and nitropyrazolylacetic acids 5f,g [26] were obtained according to published methods; pyrazoles 3a and 4b–e,h were provided by Crea-Chim.

General procedure for the synthesis of 1,3-disubstituted ureas and thioureas 1a–h.

To a solution of 454 mg (1.0 mmol) of 1-(isocyanatophenyl)adamantane or 1-(isothiocyanatophenyl)adamantane (2) in 5 mL of anhydrous DMF at 0 °C were added 1.0 mmol of aminopyrazole 3a–h and 70 mL (1.0 mmol) of Et₃N. The mixture was stirred at room temperature for 24 h. The precipitated white crystals were filtered, washed with 30 mL of EtOAc, 30 mL of 1 N HCl, and 30 mL of H₂O, and air-dried.

4-[(Adamantan-1-yl)phenyl]-3-[1-benzyl-3,5-dimethyl-1H-pyrazol-4-yl]urea (1a). Yield 381 mg (84%). M.p. 210–212 °C. IR (ν, cm⁻¹): 3318, 2901, 2847, 1643, 1572, 1451, 1301, 1246, 1095, 649. ¹H NMR (CDCl₃, δ, ppm, J, Hz): 7.7 (2H, d, J = 7.7, H Ar); 6.6 (2H, d, J = 7.8, H Ar); 7.31 (3H, t, J = 7.0, H Ph); 7.12 (2H, d, J = 6.9, H Ph); 5.51 (1H, br s, NH); 5.26 (2H, s, NCH₂Ph); 4.51 (1H, br s, NH Ar); 2.24 (3H, s, CH₃); 2.13 (3H, s, CH₃); 1.95 (3H, br s, CH Ad); 1.72–1.54 (6H, m, CH₂ Ad); 1.38 (6H, s, CH₂ Ad). ¹³C NMR (DMSO-d₆, δ, ppm): 157.1(C=O); 143.2; 137.9; 134.6; 128.5 (CH Ph); 127.3(CH Ph); 127.0 (CH Ph); 116.8; 52.3 (CH₂); 51.0 (CH₂); 39.8 (CH₂ Ad); 36.7 (CH₂ Ad); 33.7 (C Ad); 27.8 (CH Ad); 11.2 (CH₃); 9.1 (CH₃). MS (m/z, (Irel, %)): 454[M]⁺ (100). Found, %: C 76.67; H 7.52; N 12.35. C₂₉H₃₄N₄O. Calculated, %: C 76.65; H 7.49; N 12.33.

4-[(Adamantan-1-yl)phenyl]-3-[3,5-dimethyl-1-(4-methylbenzyl)-1H-pyrazol-4-yl]urea (1b). Yield 407 mg (87%). M.p. 234–236 °C. IR (ν, cm⁻¹): 3311, 2901, 2845, 1642, 1576, 1473, 1449, 1303, 1248, 1108, 730. ¹H NMR (CDCl₃, δ, ppm, J, Hz): 7.7 (2H, d, J = 7.7, H Ar); 6.6 (2H, d, J = 7.8, H Ar); 7.12 (2H, d, J = 7.7, H Ar); 7.02 (2H, d, J = 7.8, H Ar); 5.46 (1H, s, NH); 5.20 (2H, s, NCH₂Ar); 4.48 (1H, br s, NH Ar); 2.33 (3H, s, CH₃); 2.23 (3H, s, CH₃); 2.12 (3H, s, CH₃); 1.94 (3H, br s, CH Ad); 1.72–1.51 (6H, m, CH₂ Ad); 1.37 (6H, s, CH₂ Ad). ¹³C NMR (DMSO-d₆, δ, ppm): 158.2 (C=O); 144.3; 137.6; 135.9; 135.6; 130.2 (CH Ar); 128.1 (CH Ar); 117.8; 53.2 (CH₂); 52.1 (CH₂); 40.9 (CH₂ Ad); 37.8 (CH₂ Ad); 34.9 (C Ad); 28.9 (CH Ad); 21.8 (4-CH₃C₆H₄); 12.3 (CH₃); 10.2 (CH₃). MS (m/z, (Irel, %)): 468 [M]⁺ (100). Found, %: C 76.94; H 7.71; N 11.95. C₃₀H₃₆N₄O. Calculated, %: C 76.92; H 7.69; N 11.97.

4-[(Adamantan-1-yl)phenyl]-3-[3,5-dimethyl-1-(4-chlorobenzyl)-1H-pyrazol-4-yl]urea (1c). Yield 386 mg (79%). M.p. 263–265 °C. IR (ν, cm⁻¹): 3310, 2907, 2845, 1642, 1573, 1490, 1448, 1314, 1249, 1093, 1016, 803, 732. ¹H NMR (DMSO-d₆, δ, ppm, J, Hz): 7.7 (2H, d, J = 7.7, H Ar); 6.6 (2H, d, J = 7.8, H Ar); 7.40 (2H, d, J = 8.1, H Ar); 7.16 (2H, d, J = 8.1, H Ar); 7.09 (1H, s, NH); 5.74 (1H, t, J = 5.1, NH Ar); 5.18 (2H, s, NCH₂Ar); 2.02 (3H, s, CH₃); 2.01 (3H, s, CH₃); 1.93 (3H, br s, CH Ad); 1.70–1.56 (6H, m, CH₂ Ad); 1.42 (6H, s, CH₂ Ad). ¹H NMR (CDCl₃, δ, ppm, J, Hz): 7.30 (2H, d, J = 8.8, H Ar); 7.06 (2H, d, J = 8.3, H Ar); 5.50 (1H, s, NH); 5.21 (2H, s, NCH₂Ar); 4.46 (1H, br s, NH Ar); 2.23 (3H, s, CH₃); 2.12 (3H, s, CH₃); 1.95 (3H, br s, CH Ad); 1.73–1.53 (6H, m, CH₂ Ad); 1.38 (6H, s, CH₂ Ad). ¹³C NMR (CDCl₃, δ, ppm): 157.0

(C=O); 143.4; 136.8; 134.4; 131.9; 128.8 (CH Ar); 128.4 (CH Ar); 116.7; 51.4 (CH₂); 50.9 (CH₂); 39.7 (CH₂ Ad); 36.6 (CH₂ Ad); 33.6 (C Ad); 27.8 (CH Ad); 11.1 (CH₃); 8.9 (CH₃). MS (m/z, (Irel, %)): 488 [M(³⁵Cl)]⁺ (100), 490 [M(³⁷Cl)] (30). Found, %: C 71.35; H 6.80; N 11.50. C₂₉H₃₃ClN₄O. Calculated, %: C 71.31; H 6.76; N 11.48.

4-[(Adamantan-1-yl)phenyl]-3-[3,5-dimethyl-1-(4-fluorobenzyl)-1H-pyrazol-4-yl]urea (1d). Yield 406 mg (86%). M.p. 238–240 °C. IR (ν, cm⁻¹): 3318, 2901, 2847, 1643, 1604, 1573, 1510, 1481, 1449, 1314, 1297, 1248, 1230, 1157, 1104, 833, 764, 721, 532. ¹H NMR (CDCl₃, δ, ppm, J, Hz): 7.7 (2H, d, J = 7.7, H Ar); 6.6 (2H, d, J = 7.8, H Ar); 7.12 (2H, d, d, J = 8.4, J = 5.4, H Ar); 7.01 (2H, t, J = 8.5, H Ar); 5.50 (1H, s, NH); 5.21 (2H, s, NCH₂Ar); 4.47 (1H, br s, NH Ar); 2.23 (3H, s, CH₃); 2.13 (3H, s, CH₃); 1.94 (3H, br s, CH Ad); 1.72–1.50 (6H, m, CH₂ Ad); 1.38 (6H, s, CH₂ Ad). ¹³C NMR (DMSO-d₆, δ, ppm, J, Hz): 162.6 (d, J = 242.9, C-4' Ar); 158.2 (C=O); 144.5; 135.6; 135.1; 130.3 (d, J = 8.0, C-2',6' Ar); 117.9; 116.4 (d, J = 21.4, C-3',5' Ar); 52.6 (CH₂); 52.1 (CH₂); 40.9 (CH₂ Ad); 37.8 (CH₂ Ad); 34.9 (C Ad); 28.9 (CH Ad); 12.3 (CH₃); 10.2 (CH₃). MS (m/z (Irel, %)): 472 [M]⁺ (100). Found, %: C 73.75; H 6.97; N 11.89. C₂₉H₃₃FN₄O. Calculated, %: C 73.73; H 6.99; N 11.86.

4-[(Adamantan-1-yl)phenyl]-3-[3,5-dimethyl-1-(2-chlorobenzyl)-1H-pyrazol-4-yl]urea (1e). Yield 298 mg (61%). M.p. 210–212 °C. IR (ν, cm⁻¹): 3304, 2906, 2842, 1635, 1573, 1488, 1445, 1314, 1248, 1110, 1088, 1018, 830, 725, 696. ¹H NMR (CDCl₃, δ, ppm, J, Hz): 7.7 (2H, d, J = 7.7, H Ar); 6.6 (2H, d, J = 7.8, H Ar); 7.41 (1H, d, J = 7.6, H Ar); 7.25 (2H, d, J = 6.9, H Ar); 6.81 (1H, d, J = 6.9, H Ar); 5.44 (2H, s, NCH₂Ar); 5.40 (1H, s, NH); 5.17 (1H, br s, NH Ar); 2.29 (3H, s, CH₃); 2.18 (3H, s, CH₃); 1.96 (3H, br s, CH Ad); 1.73–1.50 (6H, m, CH₂ Ad); 1.44 (6H, s, CH₂ Ad). MS (m/z (Irel, %)): 488 [M(³⁵Cl)]⁺ (100), 490 [M(³⁷Cl)]⁺ (30). Found, %: C 71.36; H 6.74; N 11.43. C₂₉H₃₃ClN₄O. Calculated, %: C 71.31; H 6.76; N 11.48.

4-[(Adamantan-1-yl)phenyl]-3-[3,5-dimethyl-1-[2-(morpholin-4-yl)-2-oxoethyl]-1H-pyrazol-4-yl]urea (1f). Yield 314 mg (64%). IR (ν, cm⁻¹): 3328, 2901, 2847, 1651, 1634, 1571, 1450, 1345, 1311, 1277, 1244, 1117. ¹H NMR (CDCl₃, δ, ppm, J, Hz): 7.7 (2H, d, J = 7.7, H Ar); 6.6 (2H, d, J = 7.8, H Ar); 5.78 (1H, br s, NH); 4.93 (2H, s, NCH₂C(O)); 4.86 (1H br s, NH Ar); 3.72 (4H, t, J = 4.4, 2OCH₂CH₂N); 3.59 (4H, t, J = 4.4, 2OCH₂CH₂N); 2.89 (3H, s, CH₃); 2.21 (3H, s, CH₃); 1.95 (3H, br s, CH Ad); 1.76–1.60 (6H, m, CH₂ Ad); 1.50 (6H, s, CH₂ Ad). MS (m/z (Irel, %)): 491 [M]⁺ (100). Found, %: C 68.42; H 7.52; N 14.28. C₂₈H₃₇N₅O₃. Calculated, %: C 68.43; H 7.54; N 14.26.

4-[(Adamantan-1-yl)phenyl]-3-[1-[2-(morpholin-4-yl)-2-oxoethyl]-1H-pyrazol-4-yl]urea (1g). Yield 412 mg (89%). IR (ν, cm⁻¹): 3324, 2901, 2848, 1636, 1596, 1568, 1450, 1400, 1252, 1119, 1041, 645. ¹H NMR (DMSO-d₆, δ, ppm, J, Hz): 8.03 (1H, s, H-5 Pz); 7.7 (2H, d, J = 7.7, H Ar); 6.6 (2H, d, J = 7.8, H Ar); 7.62 (1H, s, H-3 Pz); 7.29 (1H, s, NH); 5.98 (1H, br s, NH Ar); 5.02 (2H, s, NCH₂C(O)); 3.59 (4H, s, 2OCH₂CH₂N); 3.48 (2H, s, OCH₂CH₂N); 3.46 (2H, s, OCH₂CH₂N); 1.94 (3H, br s, CH Ad); 1.71–1.58 (6H, m, CH₂ Ad); 1.44 (6H, s, CH₂ Ad). ¹³C NMR (DMSO-

d6, δ , ppm): 165.7 (C=O); 155.4 (C=O); 129.4 (CH Pz); 123.0 (C-4 Pz); 120.4 (CH Pz); 65.9 (OCH₂); 52.7 (CH₂); 50.9 (CH₂); 44.8 (CH₂); 41.8 (CH₂); 39.7 (CH₂ Ad); 36.6 (CH₂ Ad); 33.5 (C Ad); 27.7 (CH Ad). MS (m/z (Irel, %): 463 [M]⁺⁺ (100). Found, %: C 67.37; H 7.19; N 15.13. C₂₆H₃₃N₅O₃. Calculated, %: C 67.39; H 7.13; N 15.12.

4-[(Adamantan-1-yl)phenyl]-3-(1-benzyl-1H-pyrazol-3-yl)urea (1h). Yield 391 mg (92%). M.p. 169–171 °C. IR (ν , cm⁻¹): 3360, 3281, 3245, 3137, 3122, 2901, 2848, 1673, 1639, 1573, 1552, 1533, 1453, 1407, 1355, 1345, 1312, 1295, 759, 716. ¹H NMR (DMSO-d₆, δ , ppm, J, Hz): 8.76 (1H, s, H-5 Pz); 8.69 (1H, s, H-4 Pz); 7.7 (2H, d, J = 7.7, H Ar); 6.6 (2H, d, J = 7.8, H Ar); 7.31 (3H, t, J = 6.8, H Ph); 7.12 (2H, d, J = 6.9, H Ph); 7.01 (1H, br s, NH); 6.05 (1H, br s, NH Ar); 5.18 (2H, s, NCH₂Ph); 1.93 (3H, br s, CH Ad); 1.70–1.52 (6H, m, CH₂ Ad); 1.40 (6H, s, CH₂ Ad). ¹³C NMR (DMSO-d₆, δ , ppm): 159.8; 155.9 (C=O); 150.3; 138.8; 132.2 (CH Ph); 129.6 (CH Ph); 128.7 (CH Ph); 95.3; 55.6 (CH₂); 52.1 (CH₂); 40.9 (CH₂ Ad); 37.7 (CH₂ Ad); 34.5 (C Ad); 28.8 (CH Ad). MS (m/z (Irel, %): 426 [M]⁺⁺ (100). Found, %: C 76.02; H 7.09; N 13.13. C₂₇H₃₀N₄O. Calculated, %: C 76.06; H 7.04; N 13.15.

General procedure for the synthesis of amino-pyrazoles 3b–h by reduction of nitropyrazoles 4b–h.

At room temperature, 3.2 mmol of nitropyrazole 4b–h is added to a solution of 0.48 mL (9.6 mmol) of N₂H₄•H₂O in 30 mL of MeOH, followed by the addition of 22 mg (0.08 mmol) of FeCl₃•6H₂O and 160 mg (13.2 mmol) of activated carbon. The reaction mixture is brought to a boil, refluxed for 10 h, and cooled. The precipitate is filtered off, washed 3 × 20 mL with EtOH, the organic fractions are combined, and the solvent is evaporated under reduced pressure. The resulting residue is dissolved in 5 mL of H₂O and acidified with an aqueous HCl solution to pH 3–4. The resulting precipitate is filtered off, washed with 2 mL of cold H₂O and air-dried.

3,5-Dimethyl-1-(4-methylbenzyl)-1H-pyrazol-4-amine (3b). Yield 551 mg (80%), white powder. M.p. 108–109 °C. IR (ν , cm⁻¹): 3377, 3275, 3205, 2920, 1629, 1595, 1515, 1474, 1426, 1374, 1359, 1325, 1255, 1233, 1116, 830, 797, 675, 471. ¹H NMR (DMSO-d₆, δ , ppm (J, Hz): 7.10 (2H, d, J = 7.6, H Ar), 6.92 (2H, d, J = 7.7, H Ar), 5.05 (2H, s, NCH₂), 3.38 (2H, br. s, NH₂+H₂O); 2.23 (3H, s, 4-CH₃C₆H₄); 2.04 (6H, s, 2CH₃). MS (m/z (Irel, %): 215 [M]⁺⁺ (100). Found, %: C 72.35; H 8.06; N 19.68. C₁₃H₁₇N₃. Calculated, %: C 72.52; H 7.96; N 19.52.

3,5-Dimethyl-1-(4-chlorobenzyl)-1H-pyrazol-4-amine (3c). Yield 581 mg (77%), cream powder. M.p. 62–63 °C. IR (ν , cm⁻¹): 3382, 3269, 3199, 1627, 1595, 1509, 1492, 1475, 1425, 1375, 1361, 1324, 1255, 1098, 1018, 811, 797, 672, 484, 438. ¹H NMR (DMSO-d₆, δ , ppm (J, Hz): 7.38 (2H, d, J = 8.3, H Ar), 7.02 (2H, d, J = 8.4, H Ar), 5.06 (2H, s, NCH₂), 3.38 (br. s, NH₂+H₂O); 2.00 (6H, s, 2CH₃). MS (m/z (Irel, %): 235 [M(³⁵Cl)]⁺⁺ (100), 237 [M(³⁷Cl)]⁺⁺ (33). Found, %: C 61.19; H 6.04; N 17.93. C₁₂H₁₄ClN₃. Calculated, %: C 61.15; H 5.99; N 17.83.

3,5-Dimethyl-1-(4-fluorobenzyl)-1H-pyrazol-4-amine (3d). Yield 519 mg (74%), light-brown powder.

M.p. 45–46 °C. IR (ν , cm⁻¹): 3385, 3333, 1605, 1510, 1476, 1439, 1380, 1320, 1252, 1159, 1114, 949, 822, 760, 666, 520, 481. ¹H NMR (DMSO-d₆, δ , ppm (J, Hz): 7.15–7.05 (4H, m, H Ar); 5.06 (2H, s, NCH₂); 3.38 (br. s, NH₂+H₂O); 1.98 (6H, s, 2CH₃) (DMSO-d₆, δ , ppm) Hz): 161.3 (d, J = 242.6, C-4' Ar); 136.9; 134.7 (d, J = 2.9, C-1' Ar); 128.7 (d, J = 8.2, C-2',6' Ar); 125.3; 124.6; 115.2 (d, J = 21.3, C-3',5' Ar); 51.1 (NCH₂); 10.9 (CH₃); 8.5 (CH₃). MS (m/z (Irel, %): 219 [M]⁺⁺ (100). Found, %: C 65.80; H 6.42; N 19.29. C₁₂H₁₄FN₃. Calculated, %: C 65.73; H 6.44; N 19.16.

General method for the synthesis of nitropyrazolylacetic acid amides 4f,g. 7.5 Mmol of acid 5f,g is added to 25 mL of CCl₄, followed by dropwise addition of 1.1 mL (15 mmol) of SOCl₂. The reaction mixture is refluxed for 10 h, and the solvent is removed under reduced pressure. The resulting solid acid chloride residue is dried over P₂O₅ under reduced pressure and used without further purification. 1.3 mL (15 mmol) of morpholine.

3,5-Dimethyl-1-(2-chlorobenzyl)-1H-pyrazol-4-amine (3e). Yield 543 mg (72%), white powder. M.p. 98–99 °C. IR (ν , cm⁻¹): 3346, 3297, 3211, 1591, 1574, 1472, 1445, 1390, 1352, 1331, 1255, 1116, 1048, 1036, 797, 754, 748, 683. ¹H NMR (DMSO-d₆, δ , ppm (J, Hz): 7.47 (1H, d, J = 6.5, H Ar); 7.32–7.19 (2H, m, H Ar); 6.50 (1H, d, J = 7.0, H Ar); 5.12 (2H, s, NCH₂); 3.61 (br. s, NH₂+H₂O); 2.03 (6H, s, 2CH₃). MS (m/z (Irel, %): 235 [M(³⁵Cl)]⁺⁺ (100), 237 [M(³⁷Cl)]⁺⁺ (33). Found, %: C 61.07; H 5.91; N 17.88. C₁₂H₁₄ClN₃. Calculated, %: C 61.15; H 5.99; N 17.83.

2-(4-Amino-3,5-dimethyl-1H-pyrazol-1-yl)-1-(morpholin-4-yl)ethan-1-one (3f). Yield 503 mg (66%), light yellow powder. M.p. 121–122 °C. IR (ν , cm⁻¹): 3382, 3331, 3201, 2973, 2920, 2866, 1655, 1477, 1445, 1352, 1275, 1242, 1116, 1038, 962, 916, 842, 791, 631, 569. ¹H NMR (DMSO-d₆, δ , ppm (J, Hz): 4.81 (2H, s, NCH₂C(O)); 3.59–3.42 (10H, m, NH₂, 2OCH₂CH₂N); 1.9 (3H, s, CH₃); 1.96 (3H, s, CH₃). ¹³C NMR (DMSO-d₆, δ , ppm): 166.0 (C=O); 136.9 (C Pz); 126.1 (C Pz); 123.8 (C Pz); 66.1 (CH₂); 66.0 (CH₂); 50.2 (CH₂); 44.9 (CH₂); 41.8 (CH₂); 11.0 (CH₃); 8.5 (CH₃). MS (m/z (Irel, %): 238 [M]⁺⁺ (100). Found, %: C 55.30; H 7.70; N 23.74. C₁₁H₁₈N₄O₂. Calculated, %: C 55.44; H 7.61; N 23.51.

2-(4-Amino-1H-pyrazol-1-yl)-1-(morpholin-4-yl)ethan-1-one (3g). Yield 457 mg (68%), light-brown powder. M.p. 149–150 °C. IR (ν , cm⁻¹): 3406, 3344, 3241, 3123, 2955, 2856, 1649, 1594, 1459, 1410, 1360, 1269, 1241, 1113, 1039, 1019, 997, 955, 850, 818, 768, 646, 630, 591, 565. ¹H NMR (DMSO-d₆, δ , ppm (J, Hz): 6.97 (1H, s, H-5 Pz); 6.91 (1H, s, H-3 Pz); 4.89 (2H, s, NCH₂ C(O)); 3.55–3.33 (10H, m, NH₂, 2OCH₂CH₂N). ¹³C NMR (DMSO-d₆, δ , ppm): 166.0 (C=O); 131.0 (C-4 Pz); 129.7 (CH Pz); 117.8 (CH Pz); 66.0 (CH₂); 59.9 (CH₂); 52.7 (CH₂); 44.9 (CH₂); 41.8 (CH₂). MS (m/z (Irel, %): 210 [M]⁺⁺. Found, %: C 51.49; H 6.67; N 26.72. C₉H₁₄N₄O₂. Calculated, %: C 51.42; H 6.71; N 26.65.

1-Benzyl-1H-pyrazol-3-amine (3h). Yield 421 mg (76%), white powder. M.p. 64–65 °C. IR (ν , cm⁻¹): 3430, 3274, 3191, 3095, 3068, 3026, 2920, 1618, 1545, 1499, 1456, 1438, 1394, 1359, 1243, 1193, 1057, 990, 745, 730, 696, 658, 597, 582. ¹H NMR (DMSO-d₆, δ ,

ppm (J, Hz): 7.43 (1H, d, J = 2.0, H-5 Pz); 7.34–7.23 (3H, m, H Ph); 7.18 (2H, d, J = 7.1, N Ph); 5.44 (1H, d, J = 2.0, H-4 Pz); 5.03 (2H, s, NCH₂); 4.58 (2H, s, NH₂). ¹³C NMR (DMSO-d₆, δ, ppm): 155.7 (C-3 Pz); 138.4 (C Ph); 130.7 (C-5 Pz); 128.3 (CH Ph); 127.4 (CH Ph); 127.2 (CH Ph); 92.1 (C-4 Pz); 54.2 (NCH₂). MS (*m/z* (Irel, %): 173 [M]⁺ (100). Found, %: C 69.20; H 6.44; N 24.36. C₁₀H₁₁N₃. Calculated, %: C 69.34; H 6.40; N 24.26.

is added to a suspension of 7.5 mmol of the corresponding acid chloride in 15 mL of anhydrous MeCN. The mixture is stirred at room temperature for 6 h. The precipitate is filtered off, washed with 1 mL of MeCN, and crystallized from H₂O.

2-(3,5-Dimethyl-4-nitro-1H-pyrazol-1-yl)-1-morpholinoethan-1-one (4f). Yield 1.51 g (75%), white powder. M.p. 197–199 °C. IR (ν, cm⁻¹): 3423, 2974, 2864, 1648, 1570, 1496, 1469, 1421, 1376, 1363, 1275, 1242, 1116, 1070, 1041, 1005, 854, 795, 609, 573. ¹H NMR (DMSO-d₆, δ, ppm): 5.24 (2H, s, NCH₂C(O)); 3.68–3.54 (4H, m, 2OCH₂CH₂N); 3.54–3.40 (4H, m, 2OCH₂CH₂N); 2.46 (3H, s, CH₃); 2.39 (3H, s, CH₃). ¹³C NMR (DMSO-d₆, δ, ppm): 164.0 (C=O); 144.6 (C-3 Pz); 142.5 (C-5 Pz); 130.3 (C-4 Pz); 66.0 (CH₂); 65.9 (CH₂); 51.0 (CH₂); 44.7 (CH₂); 42.9 (CH₂); 13.7 (CH₃); 10.5 (CH₃). MS (*m/z* (Irel, %): 268 [M]⁺ (100). Found, %: C 49.32; H 6.06; N 21.02. C₁₁H₁₆N₄O₄. Calculated, %: C 49.25; H 6.01; N 20.88.

1-Morpholino-2-(4-nitro-1H-pyrazol-1-yl)ethan-1-one (4g). Yield 1.39 g (77%), light cream powder. M.p. 160–161 °C. IR (ν, cm⁻¹): 3449, 3127, 2962, 2863, 1655, 1533, 1509, 1474, 1402, 1334, 1307, 1272, 1236, 1218, 1035, 992, 891, 822, 756, 584. ¹H NMR (DMSO-d₆, δ, ppm): 8.77 (1H, s, H-5 Pz); 8.25 (1H, s, H-3 Pz); 5.28 (2H, s, NCH₂C(O)); 3.69–3.54 (4H, m, 2OCH₂CH₂N); 3.54–3.42 (4H, m, 2OCH₂CH₂N). MS (*m/z* (Irel, %): 240 [M]⁺ (100). Found, %: C 44.83; H 5.08; N 23.51. C₉H₁₂N₄O₄. Calculated, %: C 45.00; H 5.04; N 23.32.

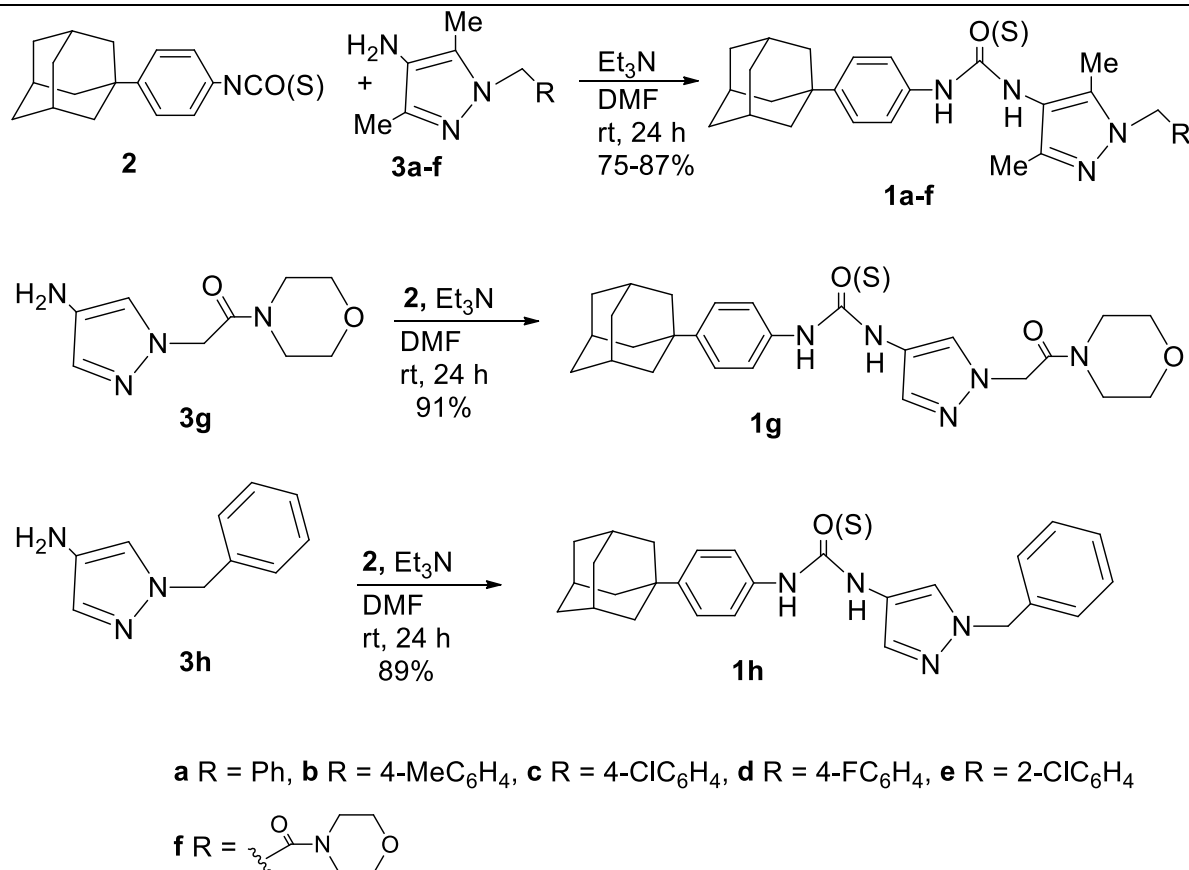
Study of the inhibitory properties of compounds 1a–h. The half-maximal inhibition concentrations (IC₅₀) for human sEH were determined using the described method [28].

To determine the solubility of compounds 1a–e,h in H₂O, series of their solutions in DMSO were prepared with concentrations ranging from 0.5 to 100 mmol/L. Then, 10 μL of the resulting solutions were added to 990 μL of a buffer solution (0.1 mol/L Na₃PO₄, pH 7.4). Thus, the final concentration of the studied compounds ranged from 5 to 1000 μmol/L, and the DMSO concentration was 1%. Solubility was determined by studying the turbidity (adsorption of light with a wavelength of 590 nm) of the resulting aqueous solutions. A buffer solution containing 1% DMSO was used as a reference.

The lipophilicity coefficient cLogP was calculated using the Molinspiration program (www.molinspiration.com).

Results and Discussion

In continuation of the work on the synthesis of adamantyl-containing 1,3-disubstituted ureas with a heterocyclic fragment [21] and the study of their properties, a series of 1,3-disubstituted ureas and thioureas 1a–h containing a pyrazole fragment were obtained for the first time (Scheme 1). The synthesis of products 1a–h was accomplished by the reaction of 1-(4-isocyanatophenyl)adamantane and 1-(4-isothiocyanatophenyl)adamantane (2) with the corresponding aminopyrazoles 3a–h in anhydrous DMF in the presence of Et₃N at a molar ratio of reagents 2:3:Et₃N equal to 1:1:1, stirring for 24 hours at room temperature. During the reaction, precipitation of 1,3-disubstituted ureas and thioureas 1a–h was observed as white crystals. After completion of the reaction, the products were filtered and washed with ethyl acetate, 1 N aqueous HCl to remove residual amine, and a small amount of H₂O. The yields of the obtained compounds 1a–1h were 67–92%. The structure of the obtained compounds was confirmed using IR spectroscopy, ¹H and ¹³C NMR spectroscopy and elemental analysis.

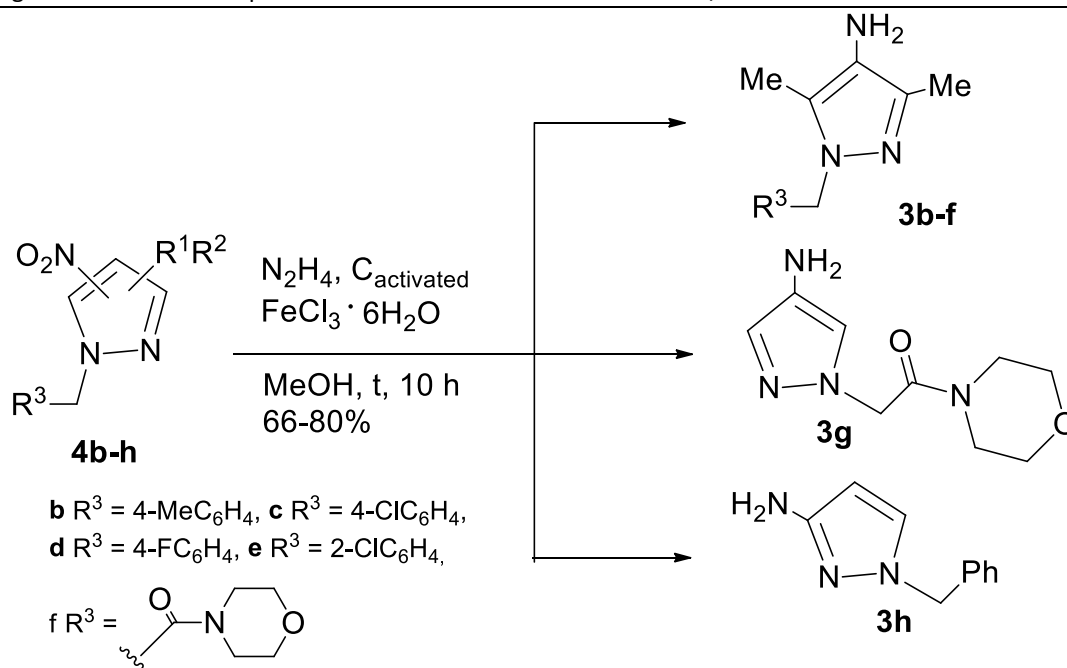


Scheme 1. Synthesis of adamantyl-containing ureas and thioureas containing a pyrazole fragment.

1-(Adamantan-1-yl)-3-(1-alkyl-1H-pyrazol-3-yl)ureas described in the literature were studied as inhibitors of human sEH (IC₅₀ 488–2512 nmol/L) and had water solubility values of 4.5–149.3 μ mol/L [22]. In order to increase the inhibitory activity against human sEH, the starting reagents for the synthesis of inhibitors were selected. The choice of isocyanate (isothiocyanate) **2** was due to the presence of a phenyl fragment between the isocyanate (isothiophane) group and the adamantyl fragment, which increases the conformational mobility of the pharmacophore fragment and facilitates better adjustment of the inhibitor in the active site of sEH [23]. Benzyl-substituted aminopyrazoles **3a–e,h**, as well as aminopyrazoles **3f,g** containing the N-[2-(morpholin-4-yl)-2-oxoethyl] group were selected as the pyrazole component (Scheme 1). Such pyrazoles are widely used in the synthesis of biologically active compounds [24]. It is known that the presence of

a methyl group, as well as halogen atoms (chlorine, fluorine) in the aromatic ring increases the inhibitory activity of compounds with respect to sEH [19]. In addition, pyrazoles **3a–f** contain methyl substituents at positions 3 and 5 of the pyrazole ring, which may help protect it from the oxidative effects of cytochromes P450. The selected series of compounds **3a–h** will allow us to study the influence of the structure of substituted pyrazoles on the properties of 1,3-disubstituted ureas (thioureas) **1a–h** and their inhibitory activity against human sEH.

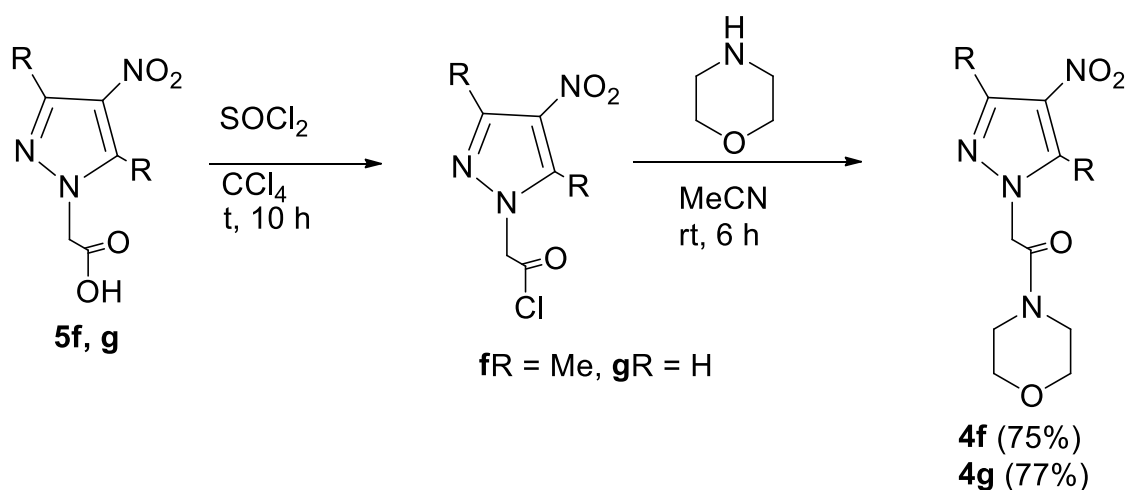
To obtain the starting aminopyrazoles **3b–h**, we used the hydrazine reduction method, which has proven itself effective for nitropyrazoles [25]. Indeed, treatment of nitro derivatives **4b–h** with hydrazine on activated carbon in the presence of FeCl₃·6H₂O as a catalyst allowed us to obtain the desired amines **3b–h** in high yields (Scheme 2).



Scheme 2. Synthesis of starting aminopyrazoles 3b-h.

Nitropyrazoles 4f,g with an N-[2-(morpholin-4-yl)-2-oxo-ethyl] substituent were obtained using a

known method from previously synthesized nitropyrazolylacetic acids 5f,g [26] (Scheme 3).



Scheme 3. Synthesis of nitropyrazoles 4f,g with N-[2-(morpholin-4-yl)-2-oxo-ethyl] substituent.

The obtained series of 1,3-disubstituted ureas 1a–h were studied as target-oriented sEH inhibitors in vitro. It was found that the inhibitory activity against human sEH for the obtained products 1a–h ranged from 16.2 to 50.2 nmol/L. Other properties of compounds 1a–e,h are presented in Table 1. For compounds 1a–e, the introduction of 4-Me, 4-Cl, 4-F, and 2-Cl substituents into the aromatic ring reduces the solubility in water. Water solubility decreases upon replacement of the

fluorine atom with a chlorine atom. The position of the substituent in the aromatic ring (para- or ortho-) has virtually no effect on water solubility. Urea based on unsubstituted pyrazole 1h is less soluble compared to 3,5-dimethylpyrazole-substituted analogs 1a–e. The obtained pyrazole-containing 1,3-disubstituted ureas 1a–e,h are better soluble in water compared to known analogues [22], which suggests their higher bioavailability.

Table 1.

Properties of 1,3-disubstituted ureas (thioureas) 1a–e,h			
Compound	Substituents on the benzene ring	Solubility in water, $\mu\text{mol/L}$	cLogP
1a	-	85 $\pm$ 3	4.80(4.96)
1b	4-Me	75 $\pm$ 2	5.25(5.57)
1c	4-Cl	65 $\pm$ 4	5.48(5.61)
1d	4-F	75 $\pm$ 3	4.96(5.03)
1e	2-Cl	65 $\pm$ 4	5.43(5.76)
1h	-	45 $\pm$ 2	4.35(4.21)

Conclusions

Thus, 1,3-disubstituted ureas and thioureas were synthesized by reacting 1-(isocyanatophenyl)-adamantane and 1-(isothiocyantophenyl)-adamantane with 3- or 4-aminopyrazoles in anhydrous DMF in the presence of Et₃N for 24 hours at room temperature. The high inhibitory activity of the resulting compounds, combined with their increased bioavailability, makes them promising for further studies as human sEH inhibitors.

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STUDY OF GENETIC PARAMETERS OF THE ESTERIFICATION REACTION

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Abstract

This article, based on a reliable analysis of theoretical and practical ideas from domestic and international scientists and specialists, examines the differentiation of genetic parameters in the esterification reaction. The importance of developing a method for determining the genetic parameters of the esterification process of citric and acetic acids with alcohols for widespread use is demonstrated. Given the deteriorating environmental situation in the world, the expansion of radiation pollution and the increasing number of cases of mass food poisoning of people and animals, it was proposed to take into account the genetic parameters of acids, fats, water, alcohols, etc., involved in the esterification process.

Keywords: Esterification reaction, genetic parameters, carboxylic acids, alcohols, esters

Introduction. The esterification reaction, which is accompanied by the interaction of organic and inorganic oxygenated acids with alcohols, results in the production of esters suitable for production and non-production-based needs. The study of the nature of esters formed by monobasic carboxylic acids with monoatomic alcohols based on the criteria of organic and inorganic chemistry, the differentiation of methods for obtaining esters and, in particular, the genetic parameters of esterification reactions, as well as the analysis of the physical and chemical properties of esters are clarified in the research of Azerbaijani and foreign scientists and specialists, and scientifically and practically important information is highlighted by electronic resources. The issues of differentiating the physical and chemical properties of the process of obtaining esters have been investigated in the books of R.A. Gasimov, N.Y. Zeynalov, and in the articles of D.S. Chicheva, E.L. Krasnykh, S.V. Levanova, S.V. Sushkova, Ju-Youl Kim, and A. Vartolomein.

Researched problem

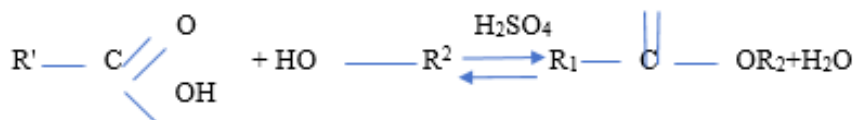
The process of obtaining complex esters is studied on Internet sites, dissertations, monographs, textbooks,

and articles, the genetic parameters of this process are determined, but the controversial issues of organic chemistry related to esterification remain beyond the attention of scientists and specialists. While investigating the causes of mass poisoning of people consuming food products, alcoholic beverages, and water, the complications of low-quality drugs in treated patients, and the death of livestock, there has been a need to conduct research into the scientific aspects of determining the genetic basis parameters of acids that are reprocessed in the esterification process.

Discussions

R.A. Gasimov considers esters of carboxylic acids as volatile, poorly soluble in water (esters with a small molecular mass are soluble in water), pleasantly fragrant substances. Most of them have a fruity and berry aroma, and at the same time, the hydrolysis of esters is carried out in acidic and alkaline environments [4, p. 24].

In electronic resources, esters are described as organic compounds formed by the interaction of carboxylic acids and alcohols, and the process of obtaining esters is called the esterification reaction.



The role of kinetic modeling in solving the problems of estimating the genetic parameters of the esterification reaction is of particular importance. N.Y. Zeynalov, a researcher of the problems of modeling the kinetics of chemical technology processes, considering the reaction mechanism in the development of a kinetic model, notes that in the course of chemical-technological processes, in the range of technological conditions that ensure the transformation in the intended direction

(temperature, pressure, composition in which the reaction takes place), the reaction rate varies as a function of the concentrations of the participating components.

$$D_A = F(C_{A2} C_{B2} \dots C_Z) k$$

From the comparative analysis of the results of the distribution of the rate concentration over time and the reaction rate expressions, the general form of the kinetic equation is formulated as follows:

$$\frac{dl_n}{d_r} = F(C_A; C_B \dots C_Z) k [8]$$

The study of the kinetic parameters of the esterification reaction involves the elucidation of the process of obtaining polyethers, biologically active substances, pharmaceuticals, and numerous additives as stabilizers and inhibitors for polymeric materials and oils from the petrochemical synthesis of carboxylic acid esters.

Based on the study of the kinetic parameters of esters, D.S. Chicheva and E.L. Krasnykh put forward a proposal to obtain raw materials for the synthesis of complex esters from natural gas in the framework of the development of gas chemistry in the direction of the development of oxosynthesis processes [5].

The study of the kinetic parameters of the esterification reaction by S.V. Sushkova allows obtaining practically important results for determining the kinetic parameters. Some kinetic parameters were determined in the process of C2 C5 esterification of citric acid with linear alcohol when sulfuric acid was used as a catalyst, and the time to 96% conversion was estimated. According to the authors, it is possible to process samples with 96-98 yields, such as tripropyl -, tributyl - and triphenylcitrate, in optimal modes, taking into account the 1.3-1.5 times lower activation parameters and the induction effect of C2 C5 alcohols, and at the same time determine density, temperature gloss, and color in Khazen units (ill. 30) for these samples in accordance with state standards [6, p. 30].

Ju-Youl Kim propose a more efficient method to determine the kinetics of the esterification reaction for a specific object using a genetic algorithm. According to them, the parameters of the reaction pattern can be successfully determined using a genetic algorithm and plant data. For this purpose, the effect of variables (temperature, pressure, monomer feed and residence time) on the conversion process should be evaluated. The reactor performance should be analyzed taking into account the degree of solubility of individual acid species in the reaction mixtures [3].

A. Vartolomei et al. reported that the maximum ester concentration can be achieved for the esterification of acetic acid with isomeric alcohols catalyzed by the commercial enzyme Lipozyme 435 at a temperature of 50 C and a flow rate of 0.16 ml/min under ultrasound assistance. The study confirms the favorable prospect of increasing the efficiency of esterification and reducing the reaction time using ultrasound in a short period of time [7].

Author's position

The substantiated provisions on the evaluation of the genetic parameters of the esterification reaction in the sources cited above are of great importance for a more detailed study of the theoretical and practical understanding of the science of organic chemistry about esters.

The structural models created by S.V. Sushkova, A. Vartolomei, etc. for determining the genetic parameters of the esterification processes of citric acid and acetic acid with alcohol can be used to determine the parameters of the process of obtaining esters of any origin. It should be noted that the studies conducted, as a rule, are limited to considering the influence of the genetic parameters of the esterification reaction on the conversion process of variables (temperature, pressure, monomer feed ratio, residence time, etc.).

Scientific studies confirm the necessity of considering the genetic basis parameters (degree of exposure to radioactive radiation and other environmental pollution) of acids used for the production of complex esters in the organic-chemical evaluation of the esterification process [1; 2].

Results

It is appropriate to summarize the analysis of the provisions substantiated by local and foreign scientists and experts, as well as the information covered by internet resources, with the following conclusions and suggestions:

First, the main parameters of the esterification reaction should include:

- increasing the temperature (accelerates the conversion, ensuring maximum total concentration);
- AI Moholol catalysts allow the esterification reaction to occur at alcohol/acid ratios (6:1 and 12:1), and the reaction can be completed in 1-2 hours.

Secondly, modeling and optimization are performed to specify the parameters of the esterification reaction rate (temperature, pressure and monomer mixing ratios). A kinetic modeling model is applied to analyze the results of enzymatic esterification. Ultrasound should be considered an important factor in ensuring the sustainability of the esterification process.

Thirdly, it is appropriate to recognize the exposure to radioactive effects of oils used to obtain complex esters, plants and fruits processed for the production of acids, and the ecological purity of water as genetic basis parameters of the transformation process.

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EARTH SCIENCES

STRUCTURE OF MESOZOIC DEPOSITS IN THE SAATLY-SABIRABAD AREA BASED ON GRAVITY SURVEYING IN COMBINATION WITH SEISMIC SURVEYING

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Abstract

This article examines the structure of Mesozoic deposits in the Saatly-Sabirabad area using gravity survey data and seismic data on the surface structure of Mesozoic deposits. As is well known, a large volume of geological and geophysical work has been conducted in the Middle Kura Depression, which includes the Saatly-Sabirabad area, revealing numerous promising structures and oil and gas deposits. The section of this area includes deposits ranging from Mesozoic to Cenozoic age. The Cenozoic stage is generally quiescent, while the Mesozoic stage is highly dislocated and therefore clearly visible in the gravity field. Seismic exploration in this region has played a significant role in understanding the structure of Mesozoic-Cenozoic deposits. However, it also faces significant challenges when used in hard-to-reach areas (rough terrain, the presence of rivers and swamps, cultivated areas, etc.). This problem is currently being addressed by correlating geological and geophysical data, particularly gravimetric and seismic data. The Geophysics Department at ASOIU has accumulated sufficient experience to conduct this type of research. The Saatly-Sabirabad area is one such hard-to-reach area. Seismic data is available for individual profiles here, along with a large amount of detailed areal gravity data. This article describes a technology for constructing structural maps based on gravity and seismic data using the MRA-COMR-COM program, as well as the results of predicting a structural map of the surface of Upper Cretaceous deposits in the Saatly-Sabirabad area in the eastern part of the Middle Kura Depression in Azerbaijan.

Keywords: Correlation, regression, structural map scheme, horizon "P", Poelogen-Neogene deposits, seismic data.

Introduction.

The Saatly-Sabirabad area is located in the eastern part of the Middle-Kura Depression. Various aspects of the Middle-Kura Depression's geological structure have been covered in the works of M.G. Agabekov, A.K. Aliyev, A.L. Ali-Zade, G.L. Akhmedov, A.A. Bakirov, N.B. Vassoevich, V.V. Weber, R.M. Gadzhiev, I.M. Gubkin, K.A. Ismailov, V.D. Kerimov, K.M. Kerimov, S.A. Kovalevsky, V.I. Kulikov, A.V. Mamedov, Sh.F. Mekhtiev, E.E. Milanovsky, M.F. Mirchinok, M.M. Radzhabov, V.V. Fedynsky, V.E. Khain, I.O. Tsimelzon, A.N. Shardanov, E.Sh. Shikhalibeyli, A.K. Shikhlinsky, A.A. Yakubov, and a number of other Caucasus researchers. In this article, the gravity field of the Saatly-Sabirabad area, which regionally belongs to the northern part of the Talysh-Vandam gravitational maximum, is analyzed to refine the geological model of the environment. This depression is characterized by the presence of a highly dislocated Mesozoic volcanosedimentary rock complex beneath monoclinaly occurring Pliocene deposits. The geological structure of this area includes deposits ranging from Quaternary to Jurassic in age. Middle-Lower Jurassic deposits were uncovered in the Saatly superdeep borehole and are expressed as a thick andesite-basalt series with a predominance of basalts. Judging by microfaunal data, Jurassic deposits were also uncovered in other areas. Lower and Upper Cretaceous deposits are developed in the Jarly, Sor-Sor, Saatly, Muradkhanly, and other areas. In the

Saatly borehole, Upper Cretaceous deposits were encountered at depths of approximately 2,800-3,500 m and are represented by alternating limestones, porphyrites, and basalts. In the adjacent Muradkhanly area, Upper Cretaceous deposits were found in both sedimentary facies and effusive formations. Paleogene-Neogene and Quaternary deposits were encountered in almost all areas of the Middle-Kura Depression and form a thick layer overlying the underlying deposits. A detailed gravity-magnetic survey confirmed and refined previously identified local anomalies and identified a number of new local gravity field features (the North Saatly, South Saatly, and Chovranly gravity maxima). The compiled gravity and magnetic anomaly maps allowed us to confirm and clarify the nature of these local anomalies. Seismic data identified three structural stages: the Mesozoic (highly dislocated), the Paleocene-Miocene (partially dislocated), and the Pliocene-Anthropogenic (quietly lying).

Reflectance survey data have revealed the upper stage. The Saatly-Dzharly tectonic zone, including the Dzharly and Saatly-Yuzhny uplifts, has been identified based on the middle Pliocene and the upper layers of the underlying sediments. CDP data have also provided a good understanding of the middle stage and the "P" seismic horizon (named after E.M. Polonsky, chief engineer of the Geophysical Trust), which characterizes the transition from Mesozoic to Cenozoic deposits. These deposits within the study area distinguish two anticline zones: the western (represented by the Zardob,

Muradkhanly, and Mil uplifts) and the eastern (including the Karadzhal, Sor-Sor, Jarly, and Saatly uplifts). CDP seismic exploration also revealed the Amirarkh, Shakhuni, Arabkubal, Karabudzhag, Saatly-Severny, Kargaly, and Myusly group of uplifts. In recent years, smaller uplifts have been identified, such as the Kargalinskaya, Gyshlaksaya, Karabatskaya, and others. A considerable number of works have been devoted to the study of the tectonics and structure of this area [9-10].

Means and methods

Tools and Methods

As is well known, seismic exploration makes it possible to study and construct reflective wave boundaries between density heterogeneities in rocks, which are associated with certain geological boundaries. However, seismic exploration is very labor-intensive and expensive. Furthermore, seismic exploration is extremely difficult to conduct in mountainous regions and areas with complex, rugged terrain, especially those with dense river networks and wetlands. Seismic exploration can also damage croplands and agricultural lands and can create various environmental problems. To study sedimentary structures and construct a structural map for a specific surface where seismic data is lacking, using available areal gravity data, statistical analysis methods are typically used. These methods are primarily used in modifications of multivariate regression analysis (MRA), correlation methods for anomaly separation (COMS), and various modifications developed for use in specific geological conditions. The technology for predicting specific boundaries or schematic maps for a specific surface using detailed and highly accurate gravity data involves several steps.

During the first stage, areal gravimetric surveys are performed in the study area, ensuring maximum accuracy of the measured data. Next, Bouguer anomaly values are calculated, taking into account corrections for elevation, the intermediate layer, and, where necessary, corrections for the terrain. A Bouguer anomaly map of the study area is then constructed, reflecting the density heterogeneities of the Earth's crustal rocks in the form of regional and local components of the complex total gravity field. It should be noted that regional and local gravity anomalies are, in turn, divided into relatively large and small ones, which reflect different exploration depths. Therefore, an important procedure for transforming the observed field is to perform transformations to separate the field into its components. For this purpose, the department has developed both individual and integrated data processing programs [7-8]. As a result of transformations using various methods and parameters, maps of local anomalies are compiled, on which reference profiles with seismic exploration

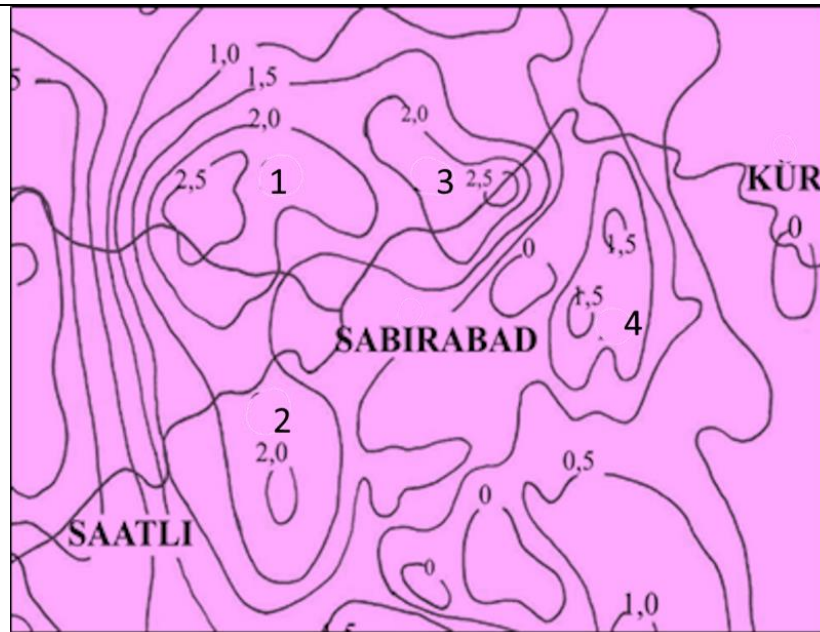
data on the depth of the studied boundary are marked. Next, seismic-gravimetric profiles are compiled, on which the values of seismic and gravimetric data are marked by quantization for subsequent preparation of the data for processing on a computer.

In the second stage, a correlation analysis is performed between seismic and gravimetric data using statistical methods. This analysis establishes correlations between seismic and gravity data and their various transforms. Regression equations are developed for optimal statistical variants, which are used to calculate the depth of the studied surface in the forecast space and to create structural diagrams of the studied surface in two- and three-dimensional versions. This process is very labor-intensive and is therefore performed on a computer using specialized software. The Geophysics Department of ASOIU has developed the corresponding MRA-COMR-COM software [1-4,6], which has been tested using actual and simulated examples.

Results and discussion

Various correlation methods and modifications of the integrated interpretation of gravity anomalies are widely used in Azerbaijan to predict geological boundaries and seismic horizons based on gravity data using statistical methods. Gravity data is typically combined with magnetic, seismic, and drilling data. When the local structure is well reflected in the gravity field, the COMR correlation separation method [5] is successfully applied. If the local structure is poorly reflected in the observed gravity field, the multivariate regression analysis (MRA) method is applied using local gravity anomalies obtained from various gravity field transformations. In the eastern part of the Middle Kuran Basin, the developed COM (combined) method, which leverages the advantages of MRA and COMR, was successfully applied and implemented in the MRA-COMR-COM Fortran program.

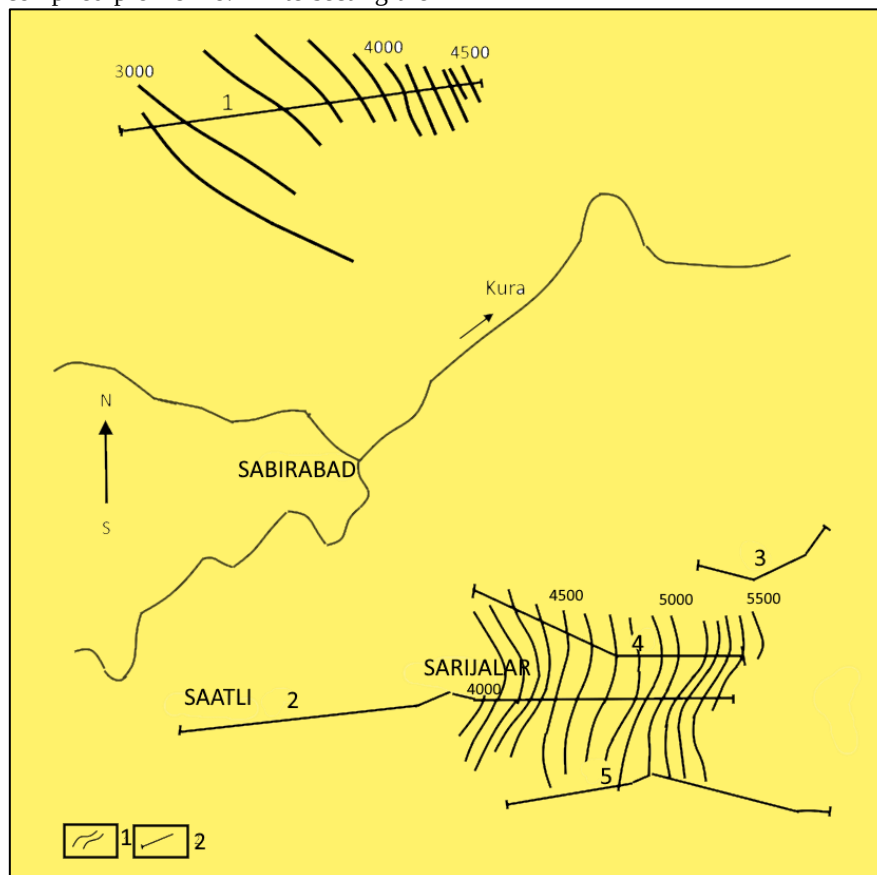
Below are the results of forecasting the seismic horizon SP-"P", characterizing the transition from Cenozoic to Mesozoic deposits, based on the integrated interpretation of gravity, seismic, and drilling data in the area of the confluence of the Kura and Araks rivers, which is difficult to access for seismic exploration. Initially, maps of local gravity anomalies of the Saatly-Sabirabad area were compiled. One of these maps - a map of the local anomaly $R(g)$ - is shown in the figure below (Fig. 1). Since the "P" horizon is well reflected in the gravity field, the COMS-A method of correlation separation of fields was used to predict the structural scheme of the area poorly studied by seismic exploration. Processing was carried out on a computer using the FORCE-FORTRAN MRA-COMR-COM program in COMR-A mode developed at the department.



Maxima: 1 - North Saatly; 2 - South Saatly; 3 - Sabirabad; 4 - East Sabirabad.
Fig. 1. Map of the local $R(g)$ anomaly for the Saatly-Sabirabad area (in mGal)

The analysis was carried out between the depth of the "P" horizon and the parameters of the gravity field Δg_{Bouger} , $R(g)$, W_{zzz} along seismic-gravimetric profiles with conditional numbers No. 2, 3, 4, 5. To increase the stability of the forecast in the northern part of the study area along the compiled profile No. 1 intersecting the

isolines of the "P" depths, the corresponding values Δg_{Bouger} , $R(g)$, W_{zzz} were taken and an analysis was carried out between their parameters (Fig. 2).



1- Depth contours along the surface of the "p" horizon;
2- Seismic profiles

Fig. 2. Saatly-Sabirabad area of the eastern part of the Middle-Kura Depression

As the results of the analysis showed, for all profiles a good correlation is observed between the depth

of occurrence of Hp and the parameters Δg_{Bouger} , $R(g)$, W_{zzz} (Table 1).

Table 1

Results of analysis for profile No. 4

N	R	NN	S	F	R_{mal}	SS	FF	R_{rem}
2	-0,98	12	41,33	0,02	6,96	32,83	33,3	0,98
3	0,96	7	45,38	0,83	7,66	31,94	35,1	0,98
4	-0,99	4	18,6	5,95	3,00	61,69	9,4	0,95
5	-0,98	8	49,96	0,14	8,44	30,84	37,7	-0,98
6	0,96	13	135,47	0,14	23,04	31,88	83,4	-0,98
7	-0,99	11	233,83	0,34	39,79	29,73	49,1	0,99
8	-0,99	3	140,10	34,00	6,75	20,04	92,3	0,98
9	-0,98	5	135,96	0,09	23,12	19,71	92,3	0,99
10	0,96	9	64,64	4,42	10,96	23,69	69,7	0,99
11	-0,99	14	963,12	0,00	163,97	18,24	107,7	0,99
12	-0,99	15	73,13	173,43	12,41	22,37	71,7	0,99

As can be seen, a good relationship is observed in the case where the length of the transformation polynomial $N=3$ and the statistical characteristics turned out to be equal:

$$S = 18, 60 ; F = 5,95 ; R_{\text{mal}} = 3,00 ; SS = 61, 69 ; FF = 9,4 ; R_{\text{rem}} = 0,95 \quad (1)$$

The analysis of correlation links involving all profiles showed that a good link is observed with the transformation length $N=3$ for the values of the statistical parameters:

$$s = 51,17 ; F = 2,51 ; R_{\text{mal}} = 3,05 ; SS = 140,04 ; FF = 34,4 ; R_{\text{rem}} = 0,98 \quad (2)$$

Below are the results of the correlation analysis taking into account all profiles (Table 2).

Table 2

Analysis results for all profiles

N	R	NN	S	F	R_{mal}	SS	FF	R_{rem}
2	-0,92	7	81,12	0,04	4,98	133,43	37,9	0,98
3	0,05	4	51,17	2,51	3,04	140,04	34,4	0,98
4	-0,94	11	13,62	14,12	0,52	256,03	10,3	0,95
5	-0,54	2	13,68	0,99	0,51	206,68	15,8	0,96
6	0,11	12	12,71	1,16	0,60	204,74	16,1	0,97
7	-0,94	8	10,95	1,35	0,72	241,25	11,6	0,95
8	-0,75	13	0,63	300,46	0,99	2967,79	0,1	-0,27
9	-0,39	5	5,29	0,01	0,94	270,13	9,2	-0,95
10	0,14	9	22,21	0,06	0,96	326,60	6,3	-0,92
11	-0,93	14	8,10	7,52	0,86	671,06	1,5	-0,77
12	-0,83	15	4,65	3,03	0,95	857,67	0,9	-0,69
13	-0,62	10	8,08	0,33	0,86	369,34	4,9	-0,91
14	-0,29	6	8,06	1,01	0,86	412,51	4,0	-0,89
15	0,14	3	45,48	0,03	2,67	140,44	34,2	0,98

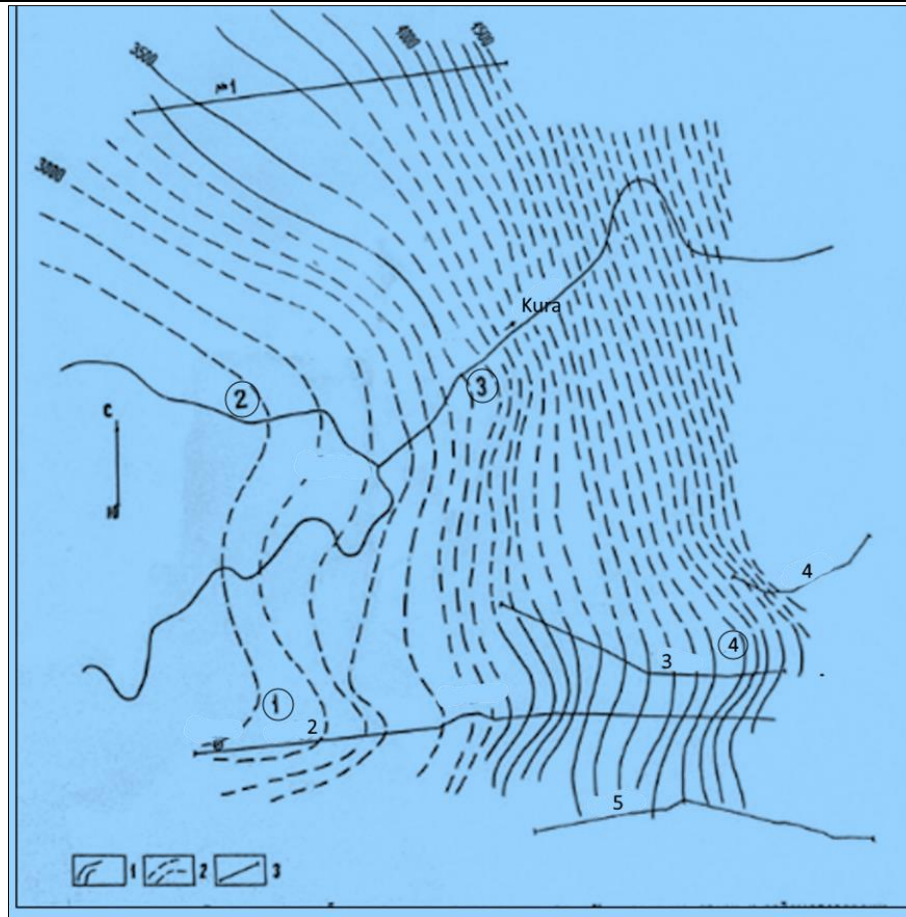
The regression equation obtained for $N = 3$ is as follows:

$$\Delta g_{\text{Bouger}} = 0,576 x - 0,198 y + 0,012 H_p, \quad (3)$$

$$\text{where } H_p = (\Delta g_{\text{Bouger}} - x 0,576 + y 0,198 y) / 0,012 \quad (4)$$

This equation was used to predict the H_p depth in the unexplored seismic portion of the Saatly-Sabirabad area, located at the confluence of the Kura and Araks

rivers. Analysis of the variation curve of H_p depth deviations from predicted values shows that the maximum of this curve corresponds to the 50-100 m interval. This allowed us to predict and construct a structural diagram with a 100 m contour interval (scale 1:50,000). The structural diagram (Fig. 3) shows a general west-to-east subsidence of the "P" horizon, against which four structural protrusions are identified: South Saatly, Saatly, Sabirabad, and North Nasimkend.



1 - SH-"P" contour lines based on seismic data; 2 - SH-"P" contour lines based on gravity and seismic data; 3 - seismic profiles (numbers are arbitrary); Highs: 1 - South Saatly; 2 - Saatly; 3 - Sabirabad; 4 - North Nasimkend.

Conclusions:

1. The geological and geophysical characteristics of the Saatly-Sabirabad area in the eastern part of the Middle-Kura Depression were analyzed in light of new geological and geophysical data. The study area comprises Mesozoic-Cenozoic deposits. The lower layer is composed of highly dislocated Mesozoic volcanosedimentary deposits, which exhibit excessive density and are therefore clearly reflected in the gravity field as local anomalies.

2. Correlations between the gravity field parameters of the study area and seismic data were analyzed. A computer-based correlation between gravity and seismic data was established for the Saatly-Sabirabad area using the FORCE-FORTRAN MRA-COMR-COM program developed at the department. Statistical analysis tables of seismic-gravimetric data for individual and all profiles were compiled. Optimal parameters were selected for generating regression equations.

3. Based on the established correlation between seismic-gravimetric data and the optimal parameters of the regression equation, depths along the surface of Cretaceous deposits were predicted on an areal basis in areas lacking seismic data. A structural map was constructed, highlighting the South Saatlinsky, Saatlinsky, Sabirabadsky, and North Nasimkendsky structural protrusions within a depth range of 3,000-4,500 m. The identified protrusions are oriented northeast and east.

The obtained results can be used to guide further seismic-gravimetric work to identify structures with potential for oil and gas production.

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ECONOMIC SCIENCES

MARKETING STRATEGIES AS A TOOL FOR MANAGING ENTERPRISE COMPETITIVENESS

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Abstract

The relevance of the topic is reflected in the fact that, according to the State Statistics Service, 758,478 enterprises were registered in Georgia in 2020, representing a 5% increase from the same period last year. The quantitative growth of companies creates competition, new markets, and forces commercial organizations to use new tools to maintain and increase sales volumes. This means that marketing in Georgian companies is moving to a new level of development. Innovations should primarily concern small and medium-sized enterprises, since they are relatively more flexible in the face of change. Marketing in such companies, as they say, is more “plastic” and allows testing various strategies for both product promotion and the company’s marketing structure. Thus, the chosen topic is relevant because of the need to develop marketing in Georgian enterprises.

Purpose and objectives of the work. The purpose of the work is to develop a marketing strategy for the company. To achieve this, it was necessary to solve the following logically interconnected tasks: (i) study the concept and specifics of marketing in the industrial sphere, the specifics of competitiveness, (ii) determination of methods for assessing competitiveness and comparison of their effectiveness; (iii) definition of the content of marketing strategy as a tool for managing competitiveness.

Subject and object of research. The object of research is marketing strategies. The subject of research is the marketing activities of the company “Elite Motors”.

The practical significance of the work lies in the potential to use the developed system to promote goods and services within a Georgian company. This strategy has been tested in the Georgian company “Elite Motors”.

Keywords: enterprise marketing strategies, marketing strategy models, functional strategies.

1. Introduction

A market economy implies the existence of competition. Today, there are several definitions of competition in the economic literature:

a) “the existence of a large number of independently acting buyers and sellers of any specific product or resource in the market”;

b) “a situation when buyers and sellers freely enter or leave markets”.

c) In the Law of Georgia “On Competition”, adopted on May 8, 2012, competition is defined as “rivalry between economic agents operating or potentially operating in the relevant market for gaining an advantage in this market”.

The law defines the organizational and legal basis for deterring, restricting, and preventing monopolistic activities and unfair competition. It aims to ensure the conditions for the creation and effective functioning of commodity markets. It does not apply to relations governed by the norms of the legal protection of inventions, trademarks, and copyrights, except in cases provided by law.

2. Variety of marketing strategies and models of their use in the company “Elite Motors.”

The basis of each marketing strategy of the company “Elite Motors” is an executive plan, by which the company achieves its set goals. Of the two theoretically known main marketing goals, at different times (depending on the strategic goals), it contains one of the following:

1. A plan for attracting clients (buyers);
2. A plan for promoting the product.

In any marketing strategy of the company “Elite Motors”, a competent analysis of the market and the sphere in which the company plans to operate is very important. Such niches may differ in size, scope, target audience, and potential profitability. In most cases, each such niche requires an individual approach from the marketing strategist.

In addition, the following factors should be taken into account: product features, target audience, market opportunities, promotion methods, distribution, and sales.

Thus, the marketing strategy of the company “Elite Motors” corresponds to the following goals:

- Assessment of real solvent demand for the product and methods of its distribution;
- Assessment of market capacity, according to which distribution will be carried out;
- Analysis of risks that may arise during product promotion and marketing;
- Analysis of real and potential products of competitors;
- Assessment of the sustainability and efficiency of product production and distribution.

The main types of marketing strategies for “Elite Motors” are: global, basic, growth, competitive, new, and functional, which we will discuss in the next chapter.

3. Results of activities carried out in 2021-2022 within the framework of the study at the company “Elite Motors.”

In 2021-2022, as in 2020, when the pandemic began, the company “Elite Motors” continued its development and even experienced significant growth.

Of course, this was also due to the company's marketing department. But it should be noted that within the framework of the study, the company's management

decided to try a new type of marketing strategy for itself- functional. Functional strategies are presented in Table 1.

Table 1.

Types of functional marketing strategies

Functional strategy name	Functional strategy name
Assortment strategy	Assortment strategy
Development strategy	Development strategy
Distribution strategy	Distribution strategy
Pricing strategy	Pricing strategy
Target market selection strategy	Target market selection strategy

When summarizing the activities and results of 2021, it turned out that the implementation of the new functional strategy gave us the following picture: The company "Elite Motors" conducted lead campaigns:

- Diesel generators,
- Nitrogen generators,
- Air compressors,
- Mekalaco-excavator loader

A lead is, first of all, the client's interest in the company and the contact established with it.

In the strict sense, a lead is a potential customer who responds to marketing communications in a way that enables the seller to understand his needs and capabilities and assess his sales potential. In this sense, a lead is not only the contacts left by a potential buyer and/or another person, but also a specific combination of the client's interests and desires, as well as the seller's belief in the prospects for further communication.

Depending on the scope and goals of the marketing campaign, the understanding of a lead's characteristics and the amount of information it contains may change. For example, market penetration can be done in several steps. It can collect different amounts of customer data (including the customer's position in the company) if we are talking about b2b marketing.

In general, any client contact information can be considered a lead, but questions arise regarding the type and qualification of the lead.

In addition, an advertising video was placed at Gldani Mall as an outdoor campaign.

Let's consider the impressive results we achieved:

- Diesel generators - 124 leads,
- Nitrogen generators - 35 leads,
- Air compressors - 117 leads,
- Mekalaco-excavator loader - 17 leads.

In exchange for the \$345 spent on the lead campaign, the company reached up to 150,000 business clients (Geostat's business database, filtered by areas of activity). The advertisement placed as a result of the outdoor campaign was seen by 360 thousand people.

Among the innovations planned for 2022, it is worth noting:

- 2 professionally edited posts per month on all pages;
- One professionally written blog per month on news;
- One blog per month about products and their features, which will highlight the positive aspects and advantages.

As for general marketing activities, the following were planned within the framework of the study:

- a) Renewing visits to BMG by starting to discuss large projects of partners;
- b) Special offer for the business club;
- c) In the best case, shooting and editing 2 videos per year about the company's path and growth prospects;
- d) Create a Wikipedia page for the company "Elite Motors" (in the coming months);
- e) In addition to TV Pirveli, on which the company's activities are systematically covered within the framework of the research (3 programs), start cooperation with several other online media;
- f) Register the company "Elite Motors" in Google My Business and create an account.

Marketing activities planned and implemented in 2022 are presented in Table 2.

In addition, the company, not within the framework of research, but based on its own business goals, conducts marketing activities for FB/INSTA, namely:

- Photo projects at locations using the equipment of "Elite Motors",
- A column of small video discussions, led by a specialist in each direction (one video per month);
- Posting blogs;
- Posting informational posts on each brand of Elite Motors;
- Live broadcasts and Q&A on Instagram, raffles.

Period	Activity
January-February	• SEO optimization (in terms of content and backend);
February	• Starting work on the creation of news;
March	• Ordering a blog.
Until the end of the year	• Visiting BMJ;
Until the end of the year	• Taking photos with partners;
Until the end of the year	• Recording a video review.
Until the end of the year	The path of "Elite Motors."

Conclusion

The strategy for promoting goods and services today is a key element of the research company's marketing plan; it sets out the goals of advertising campaigns, basic approaches to marketing communications, and tools for promoting products in the market.

1. To build a motivation system, it is necessary to introduce non-financial indicators of employee performance;

2. The salary of sales managers should depend on their professional knowledge and skills, planned and already concluded contracts, the level of customer satisfaction, etc. In addition, a system of additional bonus payments is needed, which is tied to the total value of the contract concluded by the employee, or to the importance of the client for the organization;

3. An annual bonus can be used as an effective motivation tool, the calculation of which will be based on the analysis of indicators obtained as a result of monitoring the level of customer satisfaction. For a sales manager, an annual bonus is an additional incentive to stay in the organization;

4. To manage the current situation, the head of the sales department should flexibly and promptly change the motivation goals so that they are fully consistent with the organization's ongoing goals. The change process should begin with providing employees with full information about the planned changes. The information should include: the reasons for the changes, their scope, implementation deadlines, and a list of benefits that the change will bring to employees. Employees should be well informed about all changes, since the approaches to managers in this area are special and in this market segment, even positive experience from other industries cannot be thoughtlessly used;

5. Salary alone is not enough to motivate a sales manager. Here, a direct connection between the efforts made, the results achieved, and the amount of compensation "works" much better. That is why it is important to show them the principle by which the remuneration is calculated;

6. In the process of developing an incentive system, it is necessary to take into account the level and structure of the incentive package offered by competitors under similar conditions. That is, to create an effective incentive system that drives sales growth and improves quality, it is not enough to rely solely on standard schemes. A creative approach, a deep understanding of the organization's business processes, and consideration of sales managers' personal, professional, and psychological characteristics are required.

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INTERACTION OF TRANSPORT MODES IN TRANSPORT HUBS AND THE ROLE OF MULTIMODAL LOGISTICS CENTERS**Uvalieva A.****Kobilov A.***PhD, Associate Professor, Master's Student, L.B. Goncharov Kazakh Academy of Road Construction, Almaty***ВЗАИМОДЕЙСТВИЕ ВИДОВ ТРАНСПОРТА В ТРАНСПОРТНЫХ УЗЛАХ И РОЛЬ МУЛЬТИМОДАЛЬНЫХ ЛОГИСТИЧЕСКИХ ЦЕНТРОВ****Увалиева А.Б.****Кобилев А.Х.***к.т.н., ассоциированный профессор, магистрант, КазАДИ им. Л.Б. Гончарова, г. Алматы*
<https://doi.org/10.5281/zenodo.20186429>**Abstract**

The article examines the theoretical and analytical foundations of interaction between transport modes in transport hubs under the conditions of increasing multimodal transportation, digitalization of logistics and growing requirements for coordinated cargo flow management. The study substantiates that a transport hub should be considered not only as a point of spatial intersection of transport lines, but also as an integrated transport and logistics system where material, information and organizational flows are coordinated. The economic nature of interaction between railway, road, maritime and air transport is revealed through complementarity of their technological and cost advantages, reduction of total logistics costs and improvement of supply chain sustainability. Special attention is paid to multimodal logistics centers as the most effective organizational form of transport process integration. Their role is determined through terminal, warehouse, coordination, information and service functions. The article also analyzes the main organizational forms of interaction between transport modes and summarizes foreign approaches to the development of multimodal logistics centers. It is concluded that the formation of multimodal logistics centers ensures the transition from fragmented transport interaction to integrated management of cargo flows within a unified logistics environment.

Аннотация

В статье рассматриваются теоретико-аналитические основы взаимодействия видов транспорта в транспортных узлах в условиях роста мультимодальных перевозок, цифровизации логистики и повышения требований к согласованному управлению грузопотоками. Обосновано, что транспортный узел следует рассматривать не только как точку пространственного пересечения транспортных линий, но и как интегрированную транспортно-логистическую систему, в пределах которой координируются материальные, информационные и организационные потоки. Экономическая природа взаимодействия железнодорожного, автомобильного, морского и воздушного транспорта раскрыта через комплементарность их технологических и стоимостных преимуществ, сокращение совокупных логистических издержек и повышение устойчивости цепей поставок. Особое внимание уделено мультимодальным логистическим центрам как наиболее эффективной организационной форме интеграции транспортных процессов. Их роль раскрывается через терминальные, складские, координационные, информационные и сервисные функции. Также в статье проанализированы основные организационные формы взаимодействия видов транспорта и обобщены зарубежные подходы к развитию мультимодальных логистических центров. Сделан вывод о том, что формирование мультимодальных логистических центров обеспечивает переход от фрагментарного взаимодействия транспорта к интегрированному управлению грузопотоками в едином логистическом пространстве.

Keywords: transport hub, multimodal logistics center, interaction of transport modes, multimodal transportation, logistics integration, transport infrastructure, cargo flows

Ключевые слова: транспортный узел, мультимодальный логистический центр, взаимодействие видов транспорта, мультимодальные перевозки, логистическая интеграция, транспортная инфраструктура, грузопотоки

Введение

Современная транспортно-логистическая система развивается под воздействием глобализации торговли, усложнения цепей поставок, роста контейнеризации и расширения международных транспортных коридоров. В этих условиях эффективность перевозочного процесса определяется уже не столько характеристиками отдельного вида транспорта, сколько качеством взаимодействия

транспортных подсистем в местах перераспределения потоков. Именно поэтому транспортные узлы приобретают особую значимость как пространства, в пределах которых осуществляется сопряжение железнодорожного, автомобильного, морского и воздушного транспорта, а также координация терминальных, складских, информационных и управленческих операций [1, p. 21].

В научной литературе транспортный узел традиционно рассматривается как территория пересечения транспортных линий и концентрации инфраструктурных объектов. Однако в современных условиях такое определение является недостаточным, поскольку не раскрывает его процессную, организационную и экономическую природу. Транспортный узел следует понимать как сложную транспортно-логистическую систему, в пределах которой осуществляется прием, обработка, накопление, перегрузка, хранение, перераспределение и дальнейшее продвижение грузов в условиях взаимодействия нескольких видов транспорта [3, с. 47].

Цель статьи заключается в обобщении теоретических подходов к исследованию взаимодействия видов транспорта в транспортных узлах и раскрытии роли мультимодальных логистических центров как основы интеграции транспортных процессов.

1. Теоретическое содержание транспортного узла в современной логистике

Системный подход позволяет рассматривать транспортный узел как целостную подсистему транспортно-логистической сети, включающую инфраструктуру, участников перевозочного процесса, потоки и механизмы управления. В этом случае его эффективность определяется не отдельными параметрами терминалов, путей или техники, а согласованностью всех элементов, участвующих в продвижении грузопотока [1, р. 34].

Процессный подход акцентирует внимание на последовательности логистических операций, реализуемых в пределах узла. К ним относятся прибытие груза, прием, идентификация, разгрузка, сортировка, временное хранение, перегрузка, оформление документов и отправка по дальнейшему маршруту. Следовательно, транспортный узел представляет собой пространство управления логистическими процессами, в котором особое значение имеет синхронность операций и минимизация временных разрывов [6, с. 112].

Сетевой подход раскрывает транспортный узел как ключевую точку транспортной сети, обеспечивающую связность территорий и перераспределение потоков между магистральными и локальными направлениями. В этом смысле узел выполняет не только внутреннюю логистическую функцию, но и роль структурного элемента национальной и международной транспортной системы [2, р. 56].

Экономический подход позволяет рассматривать транспортный узел как пространство концентрации логистических издержек и одновременно как источник резервов их сокращения. Существенная часть затрат в цепях поставок формируется именно в узловых пунктах, где происходят перегрузка, хранение, ожидание подачи транспорта, информационное сопровождение и координация участников. Рациональная организация узловой работы позволяет сократить продолжительность логистического цикла и повысить общую конкурентоспособность перевозок [7, с. 83].

Таким образом, транспортный узел в современной транспортно-логистической системе является не только инфраструктурным объектом, но и интеграционной платформой, где формируется качество взаимодействия видов транспорта.

2. Экономическая природа взаимодействия видов транспорта

Экономическая природа взаимодействия видов транспорта заключается в согласованном использовании преимуществ различных транспортных технологий в рамках единой логистической цепи. Отдельный вид транспорта не способен в полном объеме обеспечить одновременно минимальные затраты, высокую скорость, гибкость маршрута и устойчивость доставки. Именно поэтому в современной логистике все большее значение приобретает комплементарность транспортных систем [10, р. 118].

Железнодорожный транспорт отличается высокой провозной способностью и сравнительно низкой себестоимостью перевозок на дальние расстояния, но уступает автомобильному в гибкости доставки. Автомобильный транспорт обеспечивает доставку «от двери до двери», однако характеризуется более высокими удельными затратами на длинных плечах. Морской транспорт эффективен при перевозке крупных партий грузов, но зависит от портовой инфраструктуры и навигационных условий. Воздушный транспорт обеспечивает максимальную скорость, однако имеет высокую стоимость перевозки [12, р. 241].

Следовательно, взаимодействие видов транспорта основано на экономической комплементарности, при которой преимущества одного вида компенсируют ограничения другого. Итоговая эффективность в данном случае определяется не изолированным участком маршрута, а результативностью всей логистической цепи [11, р. 95].

Особую роль при этом играет категория совокупных логистических издержек. Эффективность взаимодействия видов транспорта должна оцениваться не только через тарифы отдельных перевозчиков, но и через полную стоимость доставки, включающую перегрузку, хранение, оформление документов, информационное сопровождение, простои и координационные расходы [14, р. 63]. Временной фактор также приобретает самостоятельное экономическое значение, поскольку сокращение сроков обработки грузов уменьшает потребность в запасах, ускоряет оборачиваемость капитала и повышает надежность цепей поставок [15, р. 121].

3. Организационные формы взаимодействия видов транспорта

В современной транспортно-логистической системе взаимодействие видов транспорта реализуется через несколько организационных форм.

Наиболее простой формой является прямое узловое взаимодействие, при котором передача груза между видами транспорта осуществляется в конкретном транспортном узле на основе технологической стыковки и двусторонних соглашений между участниками. Данная форма характерна для традиционных станций, портов и терминалов, однако при

большом количестве участников она нередко сопровождается высокой зависимостью от локальных сбоев [16, р. 74].

Более сложной формой выступает терминальная организация взаимодействия. В этом случае центральную роль играет терминал или транспортно-логистический комплекс, обеспечивающий перегрузку, хранение, консолидацию и распределение потоков. Экономическое преимущество терминальной формы заключается в стандартизации операций и сокращении координационных потерь [17, р. 208].

Операторская форма взаимодействия предполагает наличие единого логистического оператора, который организует перевозку с участием нескольких видов транспорта как комплексную услугу. Для клиента это означает получение сервиса по принципу «одного окна», а для системы — снижение транзакционных издержек и повышение прозрачности ответственности [18, р. 67].

Наиболее развитой формой является логистико-центровая модель, основанная на мультимодальных логистических центрах. В рамках данной модели транспортный узел превращается в комплексную координационную систему, объединяющую транспортные, складские, терминальные, информационные и сервисные функции. Именно эта форма наиболее полно отвечает современным требованиям интеграции транспортных процессов [19, р. 44].

Для более наглядного представления организационных форм взаимодействия видов транспорта в современной транспортно-логистической системе целесообразно представить их в графическом виде. Это позволяет показать, что взаимодействие транспортных подсистем развивается от простых локальных схем стыковки операций к более сложным интегрированным моделям, основанным на координации потоков, ресурсов и информации [10, р. 118; 11, р. 95; 15, р. 121; 18, р. 67].



Рисунок 1 – Организационные формы взаимодействия видов транспорта в транспортно-логистической системе

Как видно из рисунка 1, организационные формы взаимодействия видов транспорта различаются по глубине координации, масштабу управления потоками и уровню интеграции участников перевозочного процесса. Наиболее простой формой является прямое узловое взаимодействие, ориентированное на локальную стыковку операций в пределах конкретного транспортного узла. Более высокий уровень интеграции обеспечивают терминальная и операторская формы, в рамках которых происходит стандартизация процедур, консолидация потоков и частичная централизация функций управления [16, р. 74; 18, р. 67].

Наиболее развитый характер взаимодействия присущ логистико-центральной, коридорной и цифрово-платформенной формам. Именно они ориентированы на согласование транспортных, складских, сервисных и информационных процессов в более широком логистическом пространстве. В этом контексте логистико-центровая форма представляет наибольший научный и практический интерес, поскольку обеспечивает переход от фрагментарной передачи грузов между видами транспорта к системной координации мультимодальных потоков [17, р. 208; 20, р. 53; 21, р. 38].

4. Роль мультимодальных логистических центров в интеграции транспортных процессов

Мультимодальный логистический центр представляет собой качественно более высокую форму организации транспортного узла. Его отличие от отдельного терминала, склада или распределительного центра заключается в том, что он обеспечивает не только физическую обработку грузов, но и координацию всех основных элементов логистической цепи [20, р. 53].

Функционально мультимодальный логистический центр выполняет несколько взаимосвязанных задач:

- концентрацию и перераспределение грузопотоков;
- технологическую стыковку видов транспорта;
- координацию участников перевозочного процесса;
- информационное сопровождение операций;
- предоставление дополнительных сервисных услуг.

Экономическая роль мультимодального логистического центра выражается в снижении совокупных логистических издержек за счет сокращения времени обработки грузов, уменьшения простоев, более рационального использования инфраструктуры и повышения согласованности транспортных операций [18, р. 91].

Особое значение имеет информационная функция мультимодального логистического центра. В современных условиях высокий уровень интеграции невозможен без единой цифровой среды, включающей электронный документооборот, мониторинг статуса груза, диспетчерское управление, прогнозирование загрузки инфраструктуры и аналитическую поддержку решений [21, р. 38]. Тем самым мультимодальный логистический центр становится не только территорией переработки грузов, но и цифровым узлом управления потоками.

5. Зарубежный опыт и направления практического применения

Зарубежная практика показывает, что наиболее устойчивые модели мультимодальных логистических центров развиваются в странах, где обеспечено сочетание инфраструктурной обеспеченности, институциональной координации и цифровой интеграции. В Европе широкое распространение получили *freight villages* и *logistics centres*, ориентированные на сочетание железнодорожного и автомобильного транспорта, развитие складских и сервисных функций, а также наличие единого координационного механизма [20, р. 84].

Портово-тыловая модель, характерная для Нидерландов, демонстрирует эффективность связки «морской порт — внутренний логистический центр», позволяющей разгружать портовые зоны и перераспределять контейнерные потоки во внутренние узлы [17, р. 117]. Азиатский опыт, в том числе развитие сухих портов, показывает высокую результативность внутренней интермодальной интеграции, особенно в транзитно ориентированных экономиках [16, р. 96].

Изучение международной практики позволяет сделать вывод о том, что наиболее значимыми условиями эффективного развития мультимодальных логистических центров являются:

- выгодное транспортно-географическое положение;
- сочетание нескольких видов транспорта;
- наличие координационного ядра;
- развитая терминально-складская инфраструктура;
- цифровая интеграция процессов;
- институциональная поддержка взаимодействия участников [21, р. 42].

Заключение

Проведенный анализ показал, что взаимодействие видов транспорта в транспортных узлах является одной из ключевых основ эффективности современной транспортно-логистической системы. Экономическая природа такого взаимодействия проявляется в комплементарном сочетании преимуществ различных видов транспорта, сокращении совокупных издержек, повышении устойчивости поставок и улучшении качества транспортного обслуживания.

Установлено, что транспортный узел в современных условиях следует рассматривать как интегрированную транспортно-логистическую систему, в которой координируются не только материальные, но и информационные, организационные и сервисные потоки. Наиболее перспективной формой организации такого взаимодействия выступает мультимодальный логистический центр, обеспечивающий переход от фрагментарной передачи грузов между видами транспорта к системному управлению грузопотоками в едином логистическом пространстве.

Следовательно, развитие мультимодальных логистических центров следует рассматривать как стратегическое направление повышения эффективности транспортных узлов, усиления мультимодальной интеграции и повышения конкурентоспособности национальной транспортно-логистической системы.

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IMPROVING THE INTERACTION OF TRANSPORT MODES IN THE AKTAU HUB ON THE BASIS OF A MULTIMODAL LOGISTICS CENTER**Uvalieva A.****Kobilov A.***PhD, Associate Professor, Master's Student, L.B. Goncharov Kazakh Academy of Road Construction, Almaty***СОВЕРШЕНСТВОВАНИЕ ВЗАИМОДЕЙСТВИЯ ВИДОВ ТРАНСПОРТА В УЗЛЕ АКТАУ НА ОСНОВЕ МУЛЬТИМОДАЛЬНОГО ЛОГИСТИЧЕСКОГО ЦЕНТРА****Увалиева А.Б.****Кобилев А.Х.***к.т.н., ассоциированный профессор, магистрант, КазАДИ им. Л.Б. Гончарова, г. Алматы*
<https://doi.org/10.5281/zenodo.20186431>**Abstract**

The article substantiates practical directions for improving the interaction of transport modes in the Aktau transport hub on the basis of a multimodal logistics center. The current state of the hub is analyzed, key coordination constraints are identified, and a conceptual model of integrated transport, terminal, warehouse and digital interaction is proposed. Particular attention is paid to the organizational and technological mechanism of the multimodal logistics center, digital integration of processes, and evaluation of economic, organizational and environmental efficiency. A calculation-based assessment shows that implementation of the proposed model reduces cargo transit time through the hub, decreases storage and administrative costs, improves coordination of operations and increases sustainability of multimodal transport services. The practical significance of the article lies in the possibility of applying the proposed solutions to improve the functioning of the Aktau hub as an element of the Trans-Caspian transport corridor.

Аннотация

В статье обоснованы практические направления совершенствования взаимодействия видов транспорта в транспортном узле Актау на основе мультимодального логистического центра. Проанализировано современное состояние узла, выявлены ключевые ограничения координации, предложена концептуальная модель интеграции транспортных, терминальных, складских и цифровых процессов. Особое внимание уделено организационно-технологическому механизму функционирования мультимодального логистического центра, цифровой интеграции процессов и оценке экономической, организационной и экологической эффективности предлагаемых решений. Расчетная оценка показывает, что внедрение предложенной модели обеспечивает сокращение времени прохождения груза через узел, уменьшение складских и административных затрат, повышение согласованности операций и рост устойчивости мультимодального обслуживания. Практическая значимость статьи заключается в возможности применения предложенных решений для повышения эффективности функционирования узла Актау как элемента Транскаспийского транспортного коридора.

Keywords: Aktau hub, multimodal logistics center, transport mode interaction, cargo flow coordination, digital logistics, economic efficiency, transport corridor

Ключевые слова: узел Актау, мультимодальный логистический центр, взаимодействие видов транспорта, координация грузопотоков, цифровая логистика, экономическая эффективность, транспортный коридор

Введение

В современных условиях развитие транспортной системы Республики Казахстан все в большей степени связано с эффективностью функционирования ключевых транспортных узлов, обеспечивающих сопряжение национальных и международных маршрутов. Особое значение в этой системе приобретает узел Актау, который выполняет функцию связующего звена между морским, железнодорожным и автомобильным транспортом и одновременно выступает важным элементом Транскаспийского международного транспортного маршрута. Рост транзитных потоков, развитие контейнеризации, усиление требований к надежности доставки и цифровой прозрачности операций обуславливают необходимость перехода от фрагментарной схемы

передачи грузов к более интегрированной модели управления потоками [15, p. 121].

Несмотря на положительную динамику развития, узел Актау сохраняет ряд системных ограничений, влияющих на качество взаимодействия видов транспорта. К их числу относятся инфраструктурные ограничения, недостаточная согласованность графиков, сложность многосубъектной координации, неравномерная загрузка отдельных элементов инфраструктуры и неполная цифровая интеграция процессов. В результате часть логистических потерь формируется не на линейных участках маршрута, а именно в узловой точке, где происходят прием, накопление, перегрузка, хранение и дальнейшее перераспределение грузов [19].

Цель статьи заключается в разработке и обосновании практических направлений совершенствования взаимодействия видов транспорта в узле Актау на основе мультимодального логистического центра, а также в оценке эффективности предлагаемых решений.

1. Современное состояние и ключевые ограничения взаимодействия видов транспорта в узле Актау

Транспортный узел Актау выполняет двойственную функцию. С одной стороны, он является важнейшей точкой сопряжения морского, железнодорожного и автомобильного транспорта. С другой стороны, он выступает транзитным узлом, обеспечивающим перераспределение потоков в рамках международных транспортных маршрутов. Значимость узла определяется его положением в системе каспийских перевозок, ролью в обработке экспортно-импортных грузов, а также возможностью включения Казахстана в более широкие логистические цепи между Азией и Европой [20].

Вместе с тем анализ практики функционирования узла показывает, что его развитие сдерживается несколькими группами проблем. Во-первых, сохраняется зависимость от неравномерности прибытия грузов и транспортных средств, что приводит к перегрузке отдельных элементов инфраструктуры и возникновению временных потерь. Во-вторых, взаимодействие участников перевозочного процесса во многом остается многосубъектным и недостаточно централизованным, вследствие чего часть операций координируется не в едином контуре, а через разрозненные организационные связи. В-третьих, неполная интеграция информационных потоков снижает прозрачность обработки грузов и усложняет диспетчерское управление [18, р. 67].

Особую значимость для узла Актау имеет контейнерный сегмент. Именно он в наибольшей степени чувствителен к качеству координации, поскольку требует высокой синхронности перегрузочных операций, быстрого информационного сопровождения и устойчивого сопряжения различ-

ных видов транспорта. Это означает, что совершенствование взаимодействия видов транспорта в узле должно быть направлено не только на развитие инфраструктуры, но и на формирование единого координативного и цифрового пространства мультимодального обслуживания [21].

2. Концептуальная основа совершенствования взаимодействия видов транспорта

В качестве базового направления совершенствования предлагается формирование мультимодального логистического центра, рассматриваемого не только как инфраструктурная площадка, но и как координативное ядро транспортного узла. В этой модели морской, железнодорожный и автомобильный транспорт взаимодействуют не по принципу последовательной передачи груза между разобщенными участниками, а в рамках общего организационно-технологического контура.

Мультимодальный логистический центр в узле Актау должен обеспечивать:

- согласование графиков прибытия и отправления;
- распределение потоков по терминальным и складским зонам;
- управление очередностью обработки;
- цифровое сопровождение грузов и документов;
- мониторинг загрузки инфраструктуры;
- координацию контейнерных и общих грузопотоков.

Такой подход позволяет перейти от локальной перегрузочной логики к интегрированному управлению транспортными, складскими, сервисными и информационными процессами [17, р. 208].

Для наглядного представления практической модели совершенствования взаимодействия видов транспорта в узле Актау целесообразно представить ее в виде структурной схемы, отражающей связь транспортных потоков, внутренних блоков мультимодального логистического центра и ожидаемых результатов его внедрения.

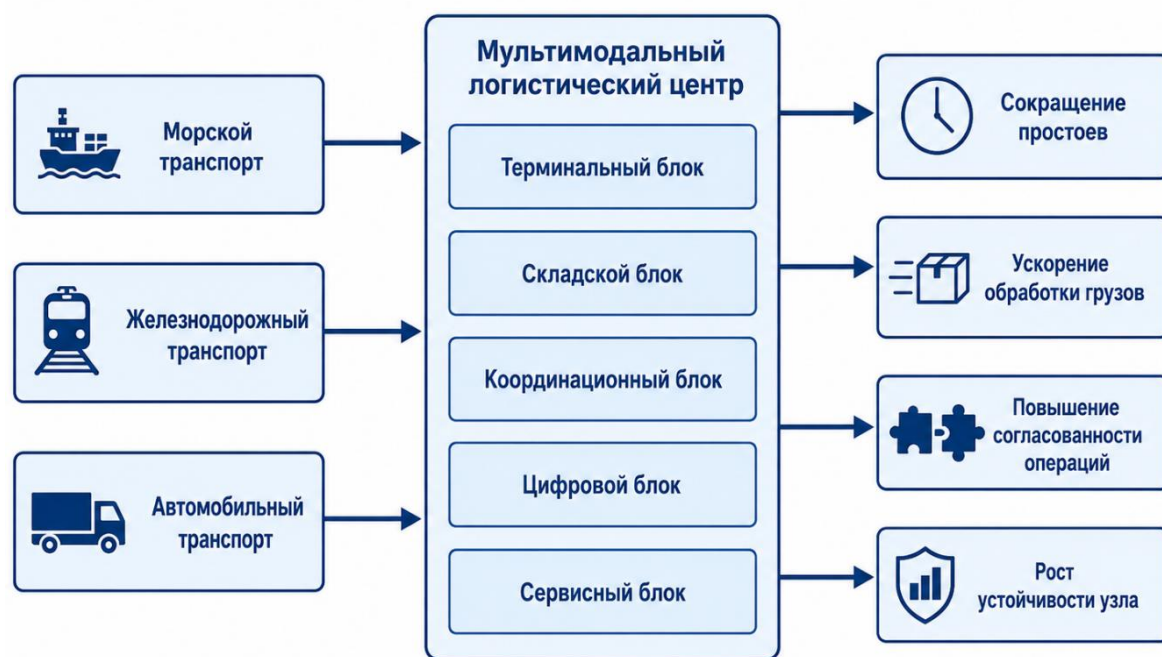


Рисунок 1 – Концептуальная модель совершенствования взаимодействия видов транспорта в узле Актау на основе мультимодального логистического центра

Как видно из рисунка 1, предлагаемая модель строится на интеграции входящих транспортных потоков в пределах единого мультимодального логистического центра, который объединяет терминальные, складские, координационные, цифровые и сервисные функции. В отличие от традиционной схемы, где каждое звено действует преимущественно в рамках собственной зоны ответственности, предложенная модель ориентирована на сквозное управление грузопотоком в границах транспортного узла. Это позволяет сократить логистические разрывы, снизить зависимость от несогласованности участников и обеспечить более устойчивую обработку грузов [18, р. 91; 21, р. 38].

3. Организационно-технологический механизм функционирования мультимодального логистического центра

Практическая реализация предложенной модели требует формирования организационно-технологического механизма, который обеспечивает последовательное прохождение груза через узел и согласование действий участников. В рамках данного механизма выделяются следующие этапы:

1. предварительное планирование мультимодальной операции;
2. прием и регистрация груза;
3. терминальная обработка;
4. складское регулирование;
5. передача на следующий вид транспорта;
6. цифровая фиксация результата и завершение операции.

Координационный центр должен выполнять функции диспетчерского регулирования и управления очередностью операций, тогда как цифровой блок обеспечивает прозрачность движения грузов, электронный документооборот и информационный обмен между участниками. Именно сочетание организационного и цифрового контуров создает условия для повышения согласованности операций и сокращения времени нахождения груза в узле.

4. Направления цифровизации и информационной интеграции узла Актау

Цифровизация транспортного узла Актау должна рассматриваться как обязательное условие эффективного мультимодального взаимодействия. Она предполагает создание единой цифровой платформы, объединяющей портовую администрацию, перевозчиков, терминальные и складские подразделения, экспедиторские компании и контролирующие органы. Основными направлениями цифровизации являются:

- электронный документооборот;
- цифровой мониторинг статуса груза;
- автоматизированное диспетчерское управление;
- контейнерная цифровая координация;
- аналитическая база оценки эффективности.

Функционально цифровая платформа должна обеспечивать регистрацию заявок, фиксацию этапов прохождения груза, резервирование ресурсов, контроль загрузки инфраструктуры и формирование аналитических показателей по времени обра-

ботки, количеству отклонений и эффективности координации. Это позволит сократить временные потери и снизить долю несогласованных операций [21, p. 38].

5. Расчетная оценка экономической эффективности

Экономическая эффективность предлагаемых мероприятий оценивается на основе расчетно-модельного подхода. В качестве базы расчета принимается общий грузооборот узла Актау в размере 4 881 000 т, а также доля грузопотока, непосредственно подпадающего под эффект внедрения модели, равная 35 %. Тогда объем охваченного грузопотока составит:

$$Q_m = 4\,881\,000 \cdot 0,35 = 1\,708\,350 \text{ т}$$

При среднем размере одной координируемой партии 500 т расчетное количество партий составит:

$$N = 1\,708\,350 / 500 = 3\,417 \text{ партий}$$

Для оценки эффекта принимается сокращение среднего времени прохождения партии груза через узел с 42 до 33 часов, то есть на 9 часов, а стоимость одного часа задержки партии — 18 000 тг. Тогда

экономический эффект от сокращения времени прохождения определяется следующим образом:

$$Et = N \cdot Ch \cdot \Delta T$$

$$Et = 3\,417 \cdot 18\,000 \cdot 9 = 553\,554\,000 \text{ тг}$$

Экономический эффект за счет сокращения складских затрат рассчитывается по формуле:

$$Es = Q_m \cdot Cs \cdot \Delta D$$

где стоимость хранения одной тонны груза в сутки составляет 220 тг, а сокращение времени складского пребывания — 0,25 суток. Тогда:

$$Es = 1\,708\,350 \cdot 220 \cdot 0,25 = 93\,959\,250 \text{ тг}$$

Экономический эффект от сокращения административно-документальных затрат определяется исходя из экономии 6 500 тг на одну партию:

$$Ed = N \cdot \Delta C_d$$

$$Ed = 3\,417 \cdot 6\,500 = 22\,210\,500 \text{ тг}$$

Итоговый совокупный эффект составляет:

$$E\Sigma = Et + Es + Ed$$

$$E\Sigma = 553\,554\,000 + 93\,959\,250 + 22\,210\,500 = 669\,723\,750 \text{ тг}$$

Для более компактного и наглядного представления результатов расчетной оценки целесообразно свести основные показатели экономической эффективности в таблицу.

Таблица 1

Сводная оценка экономической эффективности внедрения мультимодального логистического центра в узле Актау

Показатель	Значение
Общий грузооборот узла, т	4 881 000
Доля охваченного грузопотока, %	35
Объем охваченного грузопотока, т	1 708 350
Количество партий, ед.	3 417
Эффект от сокращения времени, тг	553 554 000
Эффект от сокращения складских затрат, тг	93 959 250
Эффект от сокращения документооборота, тг	22 210 500
Совокупный годовой экономический эффект, тг	669 723 750
Первоначальные вложения, тг	420 000 000
Срок окупаемости, мес.	7,6
Рентабельность внедрения, %	159,5
Экономия на 1 т груза, тг/т	392

Представленные данные показывают, что наибольший вклад в совокупный экономический эффект вносит сокращение времени прохождения груза через узел. Это подтверждает, что основным резервом повышения эффективности в мультимодальном транспортном узле является именно согласование операций, снижение простоев и сокращение логистических разрывов между этапами обработки [19; 21].

6. Организационная и экологическая эффективность предлагаемых решений

Помимо экономического результата, внедрение мультимодального логистического центра обеспечивает выраженный организационный эффект. В частности, коэффициент согласованности операций возрастает с 0,85 до 0,93, доля несогласованных операций снижается с 18 % до 10 %, а время прохождения груза через узел сокращается на 21,4 %. Это свидетельствует о повышении управляемости процесса, улучшении ритмичности обработки

грузов и росте устойчивости транспортного обслуживания.

Экологический эффект выражается в сокращении простоев транспортных средств, уменьшении числа внутриплощадочных перемещений и снижении выбросов CO₂. При сокращении среднего времени простоя транспорта с 11 до 8 часов достигается снижение простоев на 27,3 %. Дополнительно уменьшение холостого простоя автотранспорта позволяет сократить выбросы диоксида углерода примерно на 16,4 т CO₂ в год. Это подтверждает, что предложенная модель обладает не только экономической, но и экологической результативностью.

Заключение

Проведенное исследование позволило обосновать, что совершенствование взаимодействия видов транспорта в узле Актау требует перехода от фрагментарной схемы обработки грузов к интегриро-

ванной модели координации на основе мультимодального логистического центра. Предложенная модель объединяет транспортные, терминальные, складские, сервисные и цифровые процессы в рамках единого управленческого контура, что обеспечивает повышение согласованности операций, сокращение временных потерь и улучшение использования инфраструктуры.

Расчетно-модельная оценка показала, что внедрение предложенных решений является экономически обоснованным. Совокупный годовой экономический эффект составляет 669,7 млн тг, срок окупаемости — 7,6 месяца, а рентабельность внедрения достигает 159,5 %. Дополнительно установлено, что модель обеспечивает организационный и экологический эффект, выражающийся в росте согласованности операций, снижении простоев и сокращении выбросов CO₂.

Следовательно, формирование мультимодального логистического центра в узле Актау может рассматриваться как практический инструмент повышения эффективности транспортного узла и усиления его роли в системе международных транспортных маршрутов.

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USING OUTSOURCING TECHNOLOGY TO MANAGE ENTERPRISE BUSINESS PROCESSES**Darchia I.***Doctoral student at Georgian Technical University*<https://doi.org/10.5281/zenodo.20186433>**Abstract**

Today, the influence of market environmental factors on the development of business processes is not regulated; it is largely random, which inevitably leads to additional costs. In this regard, there is a growing need for a deep theoretical understanding of the role of management and improving enterprise management to ensure a new quality of economic growth. It is necessary not only to improve existing and used tools and methods, but also to increase their diversity, thereby providing the enterprise with the necessary competitive advantage. The chosen issue is especially interesting from the perspective of the methodology for regulating and developing business processes in industrial enterprises.

One of the challenges in effectively managing an industrial enterprise during Georgian economic reforms is creating a mechanism that flexibly and effectively ensures the interaction among the main elements of the logistics system: supply, production, warehousing, transportation, and distribution. The current development of economic processes urgently requires the creation of certain conditions for the unification of enterprises with different types of activity into integrated logistics chains. However, it is impossible to manage and control all processes occurring in an enterprise, especially in holding structures.

Keywords: performance management, outsourcing, logistics system.

Introduction

One of the challenges of effective management of an industrial enterprise in the process of Georgian economic reforms is the creation of a mechanism that flexibly and effectively ensures the interaction of the main elements of the logistics system, namely: supply, production, warehousing, transportation, and distribution.

The current development of economic processes urgently requires the creation of certain conditions for the unification of enterprises with different types of activities into integrated logistics chains. However, it is impossible to manage and control all processes occurring in an enterprise, especially in holding structures. Many large industrial enterprises have retained the functional structure established during the planned economy, which is focused on production, but unfortunately, such structures do not allow for market research, the formation of market niches, effective pricing policies, and financial market operations. Such enterprises find it difficult to compete with modern market-oriented companies.

To develop and improve management systems, many large industrial enterprises need to build market-oriented capabilities and implement new business models that enable them to achieve real competitive advantages. Among modern business models, outsourcing deserves special attention.

Outsourcing is the transfer of certain business or production functions that were previously performed within the enterprise to a third party. There are many definitions of outsourcing, but its essence can be reduced to a simple formula: focus all resources on activities that are important to the enterprise and transfer the remaining functions to a reliable, professional partner.

In an era of fierce competition, outsourcing can be an ideal solution that delivers cost savings, improves product quality, frees up resources to focus on the enterprise's core business, and, most importantly, ensures effective management.

Outsourcing services are popular worldwide and widely used across fields such as information technology, finance, legal support, and manufacturing. The global outsourcing market has already exceeded \$500 billion and continues to grow. Experts predict that by 2028, its volume will reach \$800 billion. This method of organizing business is most common in the United States, but in Europe and Asia, the outsourcing market's growth rate is several times higher.

According to analysts, Ford Motors currently outsources two-thirds of its components and services. As a result of outsourcing information technology at General Motors plants, information support costs have decreased from \$8 billion to \$3.5 billion, improving the quality of information services.

In today's environment, functions in which even innovation does not give the company a strategic advantage are considered suitable for outsourcing. In other words, companies outsource to focus on their core business, rather than managing cafeterias, cleaning facilities, contributing to various funds, or protecting against computer viruses. Several types of outsourcing should be distinguished: minimal, effective, and radical.

- **Minimal** outsourcing involves the elimination of purchasing, support, and service departments from the enterprise ("elimination of non-core activities"). The outsourcing services market in Georgia offers relatively simple, minimal outsourcing services (cleaning, employee catering, transportation, repair and construction work, and many others). Experience shows that the total income of a restructured enterprise quickly increases by tens of percent, while costs are significantly reduced. At the same time, output per employee increases sharply because the cost of finished products is now distributed only among the main production employees. Thus, production volume has not decreased, and the workforce has decreased by 23 times. Thus, minimal outsourcing allows you to use the

most obvious reserves and achieve almost instant results.

- **Effective** outsourcing not only eliminates non-core activities but also creates new functions. Outsourcing of accounting, auditing, consulting, and legal services has recently become increasingly popular. The so-called outsourcing (Toutsourcing - the development of information technologies for clients, as well as the creation and maintenance of reliable information systems) is very popular both in international markets and in Georgia. It is sufficient to note that more than 80% of publications on outsourcing (especially online) concern radical outsourcing - the largest segment of the outsourcing market.

- **Radical** outsourcing is the process of creating a fictitious company without production as a result of the restructuring of the enterprise. It is believed that in the future, only those companies will be considered outsourcers that: I develop new and existing products (carry out the so-called engineering), I am engaged in quality control,

- i. They seek financing and actively work in the market, including the development of market niches, the creation of brands, supervision of product promotion, etc.

- ii. They produce goods, works, and services by order and under the trademarks of companies of the first type; that is, they are outsourcers.

Thus, if a company has embarked on the path of radical outsourcing, it retains only intellectual activity; therefore, this model is fully consistent with the outsourcing principle: "I retain only what I can do better than others, and I will outsource what they do better than others."

This raises several questions:

- 1) Is it possible for an industrial enterprise to contract out and outsource the production of high-tech goods?

- 2) Is such an approach acceptable for products of high complexity?

The answers to these questions are positive. For example, the American television and tape recorder manufacturer Emerson Radio Corp. handles artistic design, technical specifications, and product promotion, while all production is outsourced to Asian subcontractors. Moreover, according to the company's president, working under a contract does not reduce efficiency. This approach is no less effective than the approach of vertically integrated companies such as Sony or Samsung, which directly control their manufacturers.

Another vivid example of a "figurative business" is the Swedish furniture company IKEA. It has

expanded its operations to unimaginable scales. Suffice it to say that in 2019, the company's turnover amounted to almost \$10 billion, and 200 million people visited its 157 giant stores worldwide. In addition to stores, the group includes 28 manufacturing plants in eight countries. However, the company itself produces only about 10% of its product range, purchasing the rest from suppliers. IKEA specialists work with manufacturers to develop product designs, identify opportunities to reduce costs and improve quality, and even ask the supplier factory's management to improve working conditions for workers or tighten safety requirements. Today, almost 50 Georgian furniture and textile factories are completely dependent on IKEA orders, even though not everyone in the Georgian market is familiar with the brand. IKEA is represented on the market only in the so-called. With "point" unitary production and full-scale intervention, it has not even begun.

With the advent of modern information technologies, new technical opportunities have emerged for the effective implementation of the "knowledge economy". Some economists argue that in the 21st century, the world will increasingly see organizations built "like the solar system": many external contractors connecting to a small native company. For example, Matthew Symonds, the editor of the technology section of the world-famous magazine *The Economist*, in his article "The Imperative Dot.com," cites Ford data. It seems that even such a large, vertically integrated company intends to focus exclusively on intellectual labor (the "knowledge economy" model).

Similar transformations are also inevitable in Georgian industrial enterprises. In the late 2000s, the transition from "survival" to "development" began. The demand for new equipment, machine tools, mechanisms, metal, and rolled products increased, as most of the equipment in our factories became obsolete.

According to "Forbes Georgia", the fixed assets of the Georgian energy sector have depreciated by more than 50%. In total, at the beginning of 2000, equipment depreciation was 60% (now it is 52%).

The experience of such companies as EMBAWOOD, GOODWILL, GeoSteel, "Sweet Country", "Kula", and many others indicates that outsourcing technologies are effective in large industrial enterprises. Therefore, the most optimal approaches are the creation of an industrial park at the enterprise, the development of clusters, the use of core competency models, and the shell structure model (Table 2).

Table 2.

Conditions for using different models of business organizational structure		
Business Structure Model	Main goals of restructuring	Conditions for using this model
Industrial Park	Eliminate the imbalance between the main and auxiliary production through business diversification. Increase revenues, strengthen sustainability.	1) Low and unstable demand for the main products of the factory and, as a result, a sharp decrease in production and sales volumes; Capacity imbalance
Cluster	Eliminate the imbalance between main and auxiliary production by minimizing the enterprise's size. Increase sustainability and reduce risks.	1) Low but stable demand for the main products of the factory and, as a result, a sharp decrease in production and sales volumes; Capacity imbalance
Dynamic Competence	Abolish auxiliary services and switch to outsourcing. Switch the business to contract or prefabricated production. Use of redundant personnel in the main production. Increase production volume, sales, and revenues.	1) High and stable demand for the main products of the factory and, as a result, a sharp increase in production and sales volumes; Shortage of personnel in the main production
Shell Structure	Eliminate production as such. Transfer of business to the "knowledge economy" based on the principles of 100% outsourcing	1) High but unstable demand and, as a result, sharp fluctuations in sales volumes; The presence of a large number of contract manufacturers (outsourcing) in the market

Thus, the outsourcing strategy allows companies to maximize their competitive advantages. It promotes the rational allocation of company resources to those businesses that are competitive and in which the company has certain advantages (technology, know-how, specialized equipment, etc.).

The use of outsourcing technology as an effective tool for developing a management system requires

addressing challenges shaped by its advantages and disadvantages. The main advantages and disadvantages of outsourcing from the client company's perspective are presented in Table 3.

The main criteria for selecting outsourcing suppliers are: trust, reliability, service, cost savings, flexibility, human resources policy, contract (deal) rigidity or liberality, internal qualification, and control.

Table 3.

Advantages and disadvantages of outsourcing from the customer's perspective	
Advantages	Disadvantages
Reducing costs	Danger of information leakage
Focusing management and personnel on the core business	Danger of transferring important functions
Improving service quality and reliability	Danger of disconnecting management from business practice
Implementing advanced technologies	Training other specialists instead of internal practice
Using the positive experience of others	Reliance on a single source
Improving control	

In our opinion, the data given in Table 4 can be used to make decisions on the scale and depth of outsourcing during the restructuring of a particular industrial enterprise.

The scale of outsourcing during an enterprise's restructuring depends on the level of development of the outsourcing services market. Let us consider this issue in more detail.

Currently, in Georgian practice, there are three types of outsourcing firms operating in the outsourcing services market, which carry out the following:

- Outsourcing of non-core activities - work and services that are usually performed by auxiliary workshops and departments;
- Outsourcing of intellectual services (legal, information, computer, consulting, recruitment, accounting, research, marketing, investment, certification, etc.);
- Outsourcing of production processes - production of parts, components, assemblies, parts of

products, or even finished products ordered by the enterprise within the framework of a production cooperation.

Non-core and intellectual activities are relatively universal, meaning they are less dependent on the specialization and technological capabilities of the industrial enterprise that uses them. Therefore, the sales market of specialized service firms (outsourcing companies) is truly colossal.

This characteristic is the main condition for the effective functioning of these outsourcing companies. In Georgia, the activities of firms that provide intellectual services to enterprises are also widespread.

Accordingly, there is a huge demand in this market, which generates supply. This market is dynamically developing and being structured.

The role of outsourcing in improving enterprise efficiency

Efficiency Factor	The degree of use of the efficiency coefficient by type of outsourcing		
	Minimal outsourcing	Effective Outsourcing	Radical Outsourcing
Focus on core competencies.	Satisfactory use of factors	Satisfactory Use of Factors	Full Factor Utilization
Reducing costs	Full factor utilization	Full utilization of factors	Full factor utilization
Using outsourcer best practices, knowledge, and technologies	Satisfactory factor utilization	Full utilization of factors	Full factor utilization
Developing the company's marketing functions	"Zero" factor utilization	Full utilization of factors	Full factor utilization
Reducing risks	Minimal factor utilization	Minimum utilization of factors	Full factor utilization
More complete use of resources	Minimal factor utilization	Satisfactory utilization of factors	Full factor utilization
Optimizing the investment structure	Minimal factor utilization	Satisfactory utilization of factors	Full factor utilization
Increasing capitalization due to the increase in the value of intangible assets	Minimal factor utilization	Satisfactory utilization of factors	Full factor utilization

Associations and unions of similar specialized firms are emerging. New specialties are emerging, and personnel are being trained for them. Professional standards and traditions are being developed, and mergers and acquisitions are taking place.

It should be noted that we have developed an algorithm that, in certain cases, guides an enterprise in using classical outsourcing technologies (Fig. 1).

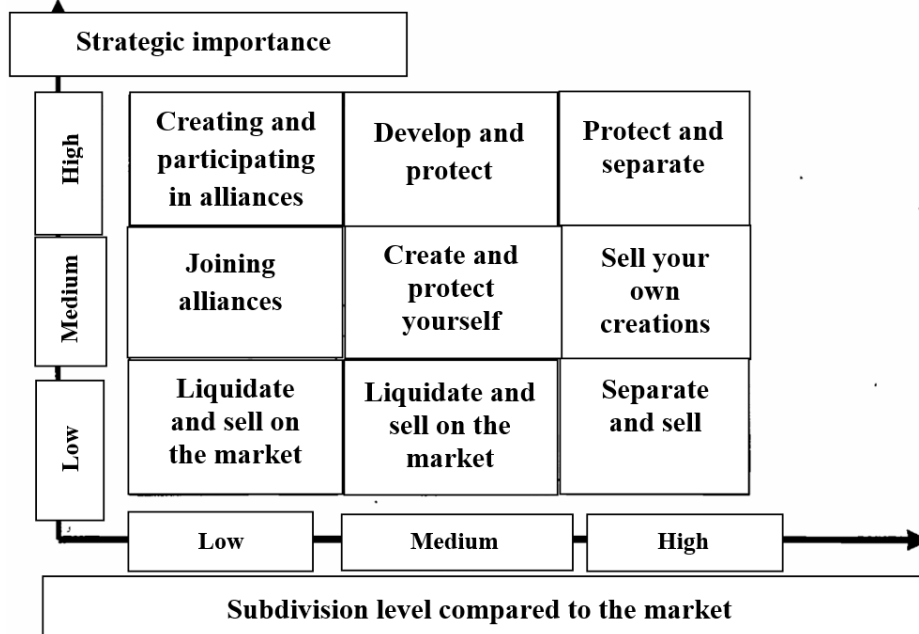


Fig. 1. Classic outsourcing matrix

Determining the need and form of outsourcing a function. A survey of heads of leading global corporations revealed the following results of IT outsourcing:

- Cost reduction by 79%;
- Focus on the core business by 75%;
- Improvement of service quality by 70%;
- Increasing competitiveness by 67%;
- Increasing shareholder returns by 62%;
- Optimizing business processes by 58%;
- Achieving global standards by 53%.

Currently, many tools are available in Georgia that enable the systematization and significant simplification of IT outsourcing work: one such tool is the ARIS

Process Cost Analyzer module, which is part of the software product family. It is used:

- for an improved and structured description of business processes;
- for analyzing business processes;
- for further improving business processes, the enterprise and its management;
- as well as for preparing for the implementation of complex information systems;
- Process cost accounting can be used as a management tool, as it can help in making general decisions in several situations, including mergers and acquisitions of enterprises.
- in testing the effectiveness of improvements;

- vii. in business processes;
- viii. In evaluating outsourcing decisions;
- ix. In evaluating alternatives when implementing standard information systems;
- x. In the implementation of business process reengineering projects;
- xi. In the management of overhead costs (in combination with total cost management).

The use of the “outsourcing matrix”. Practice has developed many methods for determining whether this

area of business should be developed within the enterprise and whether it makes sense to outsource. For this purpose, matrix analysis is most often used. The matrix can be built on any pair of indicators that characterize the enterprise's strategic position.

The most important criteria are the industry's growth rates, market share, long-term attractiveness, and competitiveness. As a result of the research, we present the author's outsourcing matrix in Figure 2.

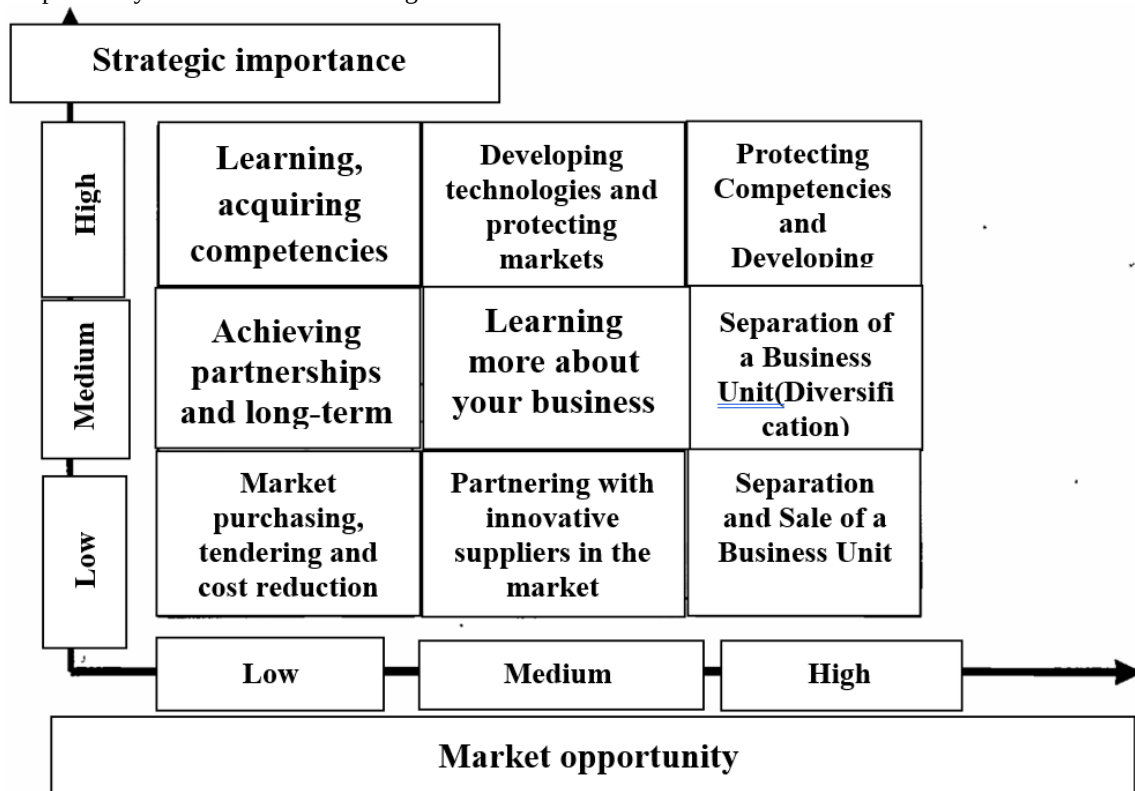


Fig. 2. Author's outsourcing matrix

The scores (high, medium and low) are calculated on two scales: the strategic importance of a given business element for the company and the assessment of the business element in relation to the external market (i.e., how well the company is performing compared to the market, how well a particular department corresponds to the current development of the industry, how qualified the employees are, etc.).

For holding structures, the “outsourcing matrix” is also built on two scales: strategic importance and market position (Figure 2). After determining the criteria for selecting outsourcing companies, it is advisable to assign weights to the criteria and select the outsourcing company using linear or multiplicative convolution.

Many large companies, to ensure sustainable development, divide non-core divisions into independent business units. This logical step allows them to reduce costs and concentrate efforts on core business areas.

As a rule, service units are separated from the main production units and subsequently become independent legal entities, while the parent companies retain ownership and operational control over their activities.

In the vast majority of cases, there is no attempt to radically transform the operational and organizational structures of service companies that continue to operate

according to traditional principles, maintaining closed monopoly relations with their main customer - the parent company.

When deciding on outsourcing the business functions of an industrial enterprise, the following sequence should be observed.

1. Internal business processes are classified as core, core/non-core, and auxiliary. Core processes are those that add value to the company's main final product. Core/non-core processes are those that create additional value for a non-core product that horizontally diversifies the business and does not correspond to the company's strategic plans to remain in the industry. Supporting processes include functions that provide support, such as maintenance, construction, transportation, office work, IT, and accounting.

2. **Assessing the feasibility of separating a division from the parent company.** At this stage, a market analysis is conducted for services comparable to those provided by the division that has been separated. The need for this analysis is related, first, to the risk of creating a monopoly and dependence on a vital supplier, and second, to developing a viable business plan for new companies. Tenders can be used as a tool for analyzing the service market for parent companies. The

second component of this stage is an analysis of the performance of the separated divisions and a forecast of their independent functioning.

3. A detailed strategy is developed for each business unit. At this stage, the management system is improved, an effective financial structure is created, and operational activities are optimized. In some cases, the separated divisions require investments in their own capabilities. For a company to function in an open, competitive market, it is also necessary to establish development, marketing, and sales functions. After the auxiliary unit is outsourced, it will no longer be accountable to the production manager, chief engineer, or other employees of the parent enterprise. This unit will have its own goals and objectives. To minimize the risk of violations in the main business process, it is initially necessary to establish relationships based on the "customer-supplier" principle. The following processes should be strictly regulated on the main production side:

- Procurement planning and control: what and when to receive from the outsourcing company;
- Requirements documentation: consolidation of commercial conditions and technical requirements;
- Evaluation of outsourcing companies;
- Conclusion of contracts;
- Monitoring of contract performance: ensuring that performance indicators meet contractual requirements.

4. Procurement planning and control. Procurement planning activities should identify service needs and service delivery schedules. At this stage, the total cost of the purchased services is determined based on their characteristics, prices, and delivery times. Special attention should be paid to issues that are critical to the quality, timing, and cost of the company's final product. This means that work should be done to assess and minimize risks associated with the primary production facility's support functions.

All products and services for the primary company should be considered purchased, regardless of whether they are obtained from independent suppliers or from internal support business units. In both cases, the requirements should be the same: sufficient time should be allocated during the procurement process to evaluate service providers, study requirements, and review contracts. To ensure adequate control over procurement, delivery progress should be compared with the planned delivery schedule, and, if necessary, appropriate measures should be taken.

5. Document requirements. Documented requirements define the scope of delivery, service characteristics, relevant quality management requirements, and supporting documentation. They should also include service delivery timelines and access rights to the outsourcer's premises. In some cases, traceability and communication channel requirements are specified. The structure of the documents should facilitate the obtaining of accurate, comparable, and complete responses from potential suppliers.

6. Supplier evaluation. To evaluate suppliers, companies establish procedures for identifying poten-

tial suppliers, evaluating existing suppliers, and assessing their ability to deliver the required products. These procedures include:

- Analysis of service quality, pricing, and problem solving;
- Audit of outsourcer management systems, as well as an assessment of their potential ability to provide the required services effectively and on schedule;
- Verification of recommendations to assess customer satisfaction;
- Financial assessments to ensure the viability of the supplier;
- Proposals;
- Assessment of logistical capabilities.

The results of the supplier evaluation are presented in a scoring system that takes into account not only the indicators themselves, but also their importance (weight). The most important factors are compliance with established requirements, compliance with deadlines, and quality of service. When summing up the evaluation, the scores for each parameter are summed up, and one of three decisions is made:

- 1) The supplier can cooperate.
- 2) The supplier is conditionally able to cooperate and is subject to further evaluation.
- 3) The supplier is not able to cooperate.
- 4) Auditing is an important element in assessing the effectiveness of further interactions.

Contracting. When evaluating the tender results, all deviations from the requirements specified in the outsourcer's proposal should be identified and accounted for. The evaluation of the tender results should be based not only on price, but also on other cost indicators, such as inspection costs, quality audits, and deviation correction.

In addition, attention should be paid to the quality of technical performance and appropriate performance guarantees. To ensure an objective tender, measurable selection criteria have been developed: the impact of any compromises on quality should be fully considered before the contract is awarded. Contract documents should be reviewed to reflect any negotiations that may have occurred before the contract's conclusion.

7. Contract management. Contract management should involve establishing appropriate contractual relationships and integrating the data from these relationships into the company's overall management system. Regular verifications should be conducted to ensure that ancillary production performance meets the contract requirements. The results of these verifications should be communicated to all interested parties, and any agreed-upon action should be taken. To facilitate interaction with outsourcers in conflict situations, companies may find it appropriate to develop and adhere to regulations for each supplier category.

8. Quality management of ancillary production. Companies can ensure consistent quality in ancillary production services by implementing and certifying a Quality Management System (QMS) for ancillary production. Creating a QMS is a task that integrates the organization's overall management with the ideology of quality as its highest strategic goal. Although outsourcing is a relatively new type of service on the Georgian

market, this method of organizing business has significant development prospects. This is evidenced by the growth rate of outsourcing by the largest Georgian enterprises.

Conclusion

Thus, the active and widespread use of outsourcing technologies supports the implementation of economic strategies in an unstable market environment, improves the quality of industrial enterprises' products, enhances their active involvement in the international division of labor, and increases production efficiency, thereby helping to ensure economic stability.

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ENHANCING ENERGY EFFICIENCY IN THE CONTEXT OF INNOVATIVE MODERNIZATION OF THE AZERBAIJANI ECONOMY**Karimov K.***Associate Professor, Internationally Certified Economist,
Azerbaijan State Oil and Industry University, Baku, Azerbaijan***Jafarova N.***Head teacher**Azerbaijan State Oil and Industry University, Baku, Azerbaijan***Safarli Z.***Assisient.**Azerbaijan State Oil and Industry University, Baku, Azerbaijan*<https://doi.org/10.5281/zenodo.20186435>**Abstract**

This article examines the development of a mechanism to stimulate energy conservation and enhance energy efficiency as a key direction of the innovative modernization of the national economy during its transition to a new technological paradigm. The study explores the strategic prospects for the development of the Azerbaijani economy, substantiates the role of energy conservation and energy efficiency within the system of priorities for its innovative modernization, and evaluates the extent to which the energy factor influences overall economic performance.

The paper presents forecasting models and simulates the dynamics of the economy's energy intensity under alternative scenarios of changes in the external political and economic environment. It further identifies the mechanisms of interaction between innovation-driven development processes and energy conservation and efficiency improvements across different levels of economic governance. Particular attention is devoted to the conceptual and methodological foundations for designing a mechanism to promote energy conservation and improve energy efficiency at multiple levels of governance, positioning it as a central component of the innovative modernization of the Azerbaijani economy in the context of its transition to a new technological paradigm.

Keywords: national economy, energy efficiency, innovative development, modernization, model

I. Introduction

The issue of transitioning the national economy to an innovation-driven development path has received sustained attention at all levels of governance for many years. As a result of the measures undertaken, the country has established the foundations of a legislative and regulatory framework governing various aspects of innovation management and the protection of intellectual property rights. Significant efforts have been directed toward supporting state corporations and creating specialized development institutions, particularly research and innovation funds endowed with substantial financial resources for subsequent investment in promising innovation projects. The practice of developing sectoral innovation development programs has also become widespread.

However, a number of unresolved systemic problems in this domain continue to constrain Azerbaijan's transition to a trajectory of sustainable innovation-driven growth. In the context of the emerging new technological paradigm in the global economy, these constraints may further weaken the country's competitive position. The current situation necessitates a substantial intensification of efforts aimed at advancing the national economy along an innovation-based development path. One of the critical challenges in this regard is improving energy efficiency.

This challenge is largely обусловлено тем, что уровень потребления энергетических ресурсов на единицу валового внутреннего продукта в Азербайджане, по различным оценкам, по-прежнему в three to five times higher than in developed economies. Moreover, in recent years this gap has not narrowed; on the contrary, it shows a tendency to widen. Accordingly, the present study is focused on addressing both theoretical and applied issues related to enhancing energy efficiency at various levels of economic governance as a key direction of the innovative modernization of the Azerbaijani economy in the context of its transition to a new technological paradigm.

International ranking assessments serve as clear indicators of the success and shortcomings in organizing and supporting innovation activities across national economies. For instance, the Global Innovation Index (GII), published since 2024 through the joint efforts of Cornell University, INSEAD Business School, and the World Intellectual Property Organization, ranks 128 national economies according to their level of innovation development, thereby enabling the identification and dissemination of best global practices in fostering innovation processes.

As evidenced by the data presented in Figure 1, Azerbaijan's position in this ranking demonstrates a positive trend, reflected in its advancement from 98th place in 2012 to 77th place in 2024.

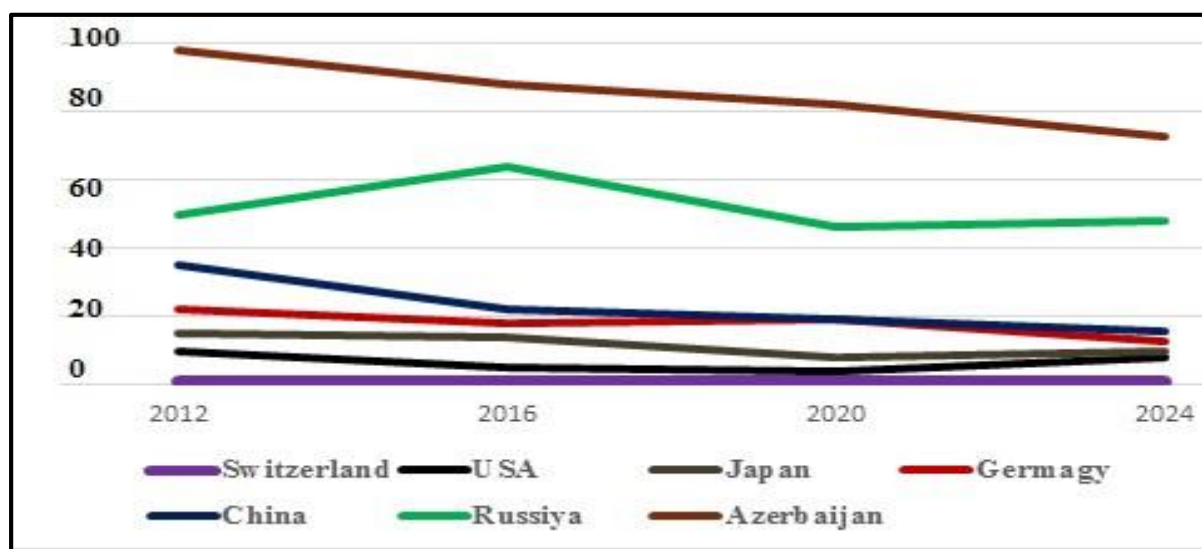


Figure 1. Comparison of countries' positions in the Global Innovation Index

However, a closer examination of the Global Innovation Index (GII) reveals that its values have remained largely unchanged over at least the past eight years. When comparing Azerbaijan's progress within the GII with the dynamics of a number of other countries, forecasts regarding its potential entry into the Top 25 of the ranking—even in the long term, not to mention more ambitious targets—appear rather uncertain.

Similarly to the GII and the Human Capital Index, the Global Competitiveness Index (GCI) has also remained broadly stable. Improvements in Azerbaijan's ranking positions in certain years are explained not so much by an enhancement in the quality of the business environment, but rather by a relative deterioration in other countries, which consequently lost their positions in the ranking.

The situation reflected in international rankings can largely be explained by the fact that, for a long period, the country has attempted to address its innovation development challenges by following a so-called catch-up development model. This approach has been based on supporting technological areas that had already been disseminated globally and had formed corresponding international markets [1–4].

While this model may produce certain positive outcomes in the medium term, it is unlikely to significantly alter the long-term dynamics of innovation processes, as it effectively confines technological development to areas that are already at either the maturity or decline stage of their product life cycle.

The inefficiency of the chosen innovation development model has been further exacerbated by the traditionally weak demand for innovative developments in the domestic Russian market. On the one hand, this was due to the long-standing availability of budget revenues derived from the export of raw materials, primarily oil and gas. On the other hand, it reflected the highly cautious attitude of most domestic enterprises towards innovative projects even with a moderate level of risk, which, under relatively low competitive pressure in many domestic goods and services markets, were often perceived as a threat to established business practices.

As a result, the limited number of initiatives undertaken by producers was mainly focused on the acquisition of ready-made foreign technologies and equipment, which can only conditionally be classified as innovative.

In this context, the structure of investment in innovation activity has predictably been shaped in such a way that the most important source of funding for research activities—forming the core of the innovation process—has been, and continues to be, the state budget.

Accordingly, the relatively low share of research and development expenditures in GDP is not surprising. According to this indicator, Azerbaijan ranked only 84th globally in 2024, with a value of 1.13%.

II. The impact of energy conservation and energy efficiency improvement processes on the innovative development of national economies.

Energy conservation and energy efficiency improvement have, in recent years, become one of the most important strategic directions in the economic development of many countries. In the context of global economic integration, this direction has gained particular significance, as it enhances the competitiveness of national economies.

A key indicator used to assess the effectiveness of state policy in the field of energy conservation and energy efficiency is the dynamics of energy intensity of gross domestic product (GDP). It should be noted that changes in GDP energy intensity are influenced not only by energy policy measures, but also by a range of other factors, including structural shifts in the economy, energy price dynamics, and technological aspects of energy production, transmission, distribution, and consumption. In economically developed countries, the economic structure is characterized by a large service sector; therefore, *ceteris paribus*, their GDP energy intensity is significantly lower than in economies dominated by heavy industry.

Based on the analysis of data on the energy intensity of national economies in developed countries, a clearly observable trend has been identified: a decline in gross inland energy consumption relative to GDP.

According to Eurostat, the Organisation for Economic Co-operation and Development (OECD), and the European Environment Agency, energy intensity decreased in all G20 countries over the period 2010–2024, with the exception of Mexico, where it remained stable. Over the period 2015–2025, significant energy efficiency measures were implemented in Indonesia, India, the United States, and Japan. As a result, energy intensity in these countries decreased by almost 20%. At the same time, Japan, Türkiye, and European Union (EU) countries demonstrate the lowest levels of energy intensity [5–9].

In our view, the reduction in energy intensity across G20 economies, along with decreases in indicators such as per capita gross inland energy consumption by fuel type and final energy consumption, is primarily the result of effective energy conservation and energy efficiency policies implemented by these countries. In contrast, Azerbaijan, despite the measures adopted, has maintained its position as one of the most energy-intensive economies among major global states.

One of the main drivers of declining energy intensity in developed economies is the widespread application of advanced technologies and modern equipment. In turn, this has been facilitated by the inclusion of energy conservation and energy efficiency as strategic priorities within national science and technology development policies.

According to OECD data, average government expenditure on R&D in the energy sector among member countries accounts for approximately 4.5% of total public R&D spending, while environmental R&D accounts for nearly 1.7%. Countries that have achieved the most significant reductions in energy intensity have simultaneously made substantial investments in energy-related R&D. At first glance, the Republic of Korea appears to be an exception in this group. It invests more than USD 2 billion annually in energy R&D (or 8.8% of total R&D expenditure). However, its energy intensity decreased by only 5% over the period 2010–2024. In this context, it should be taken into account that South Korea has experienced relatively high economic growth rates (average annual real GDP growth of 4% in 2000–2024), a high share of energy-intensive industries in its economy, and a near-complete dependence on imported energy resources.

It should also be noted that the relative level of budget expenditures in Azerbaijan in the considered area is significantly lower than in most of the countries under review. An even higher level of R&D expenditure in the energy sector is observed in Japan. In relative terms, its expenditure amounts to 12.1%, while in absolute terms it reaches USD 4,800 million.

All of the above may serve as evidence supporting the conclusions of domestic researchers that the decline in the energy intensity of Azerbaijan's economy over the considered period was not the result of efforts aimed at the innovative modernization of energy-intensive industries, but rather due to other factors, including structural shifts in the economy. Although innovation-driven modernization of infrastructure was implemented, it remained local in nature and was concentrated in a limited number of high-tech industrial clusters.

At the same time, an increase in the innovation potential of G20 countries has been observed in recent years. As shown by data from the INSEAD Business School, Cornell University, and the World Intellectual Property Organization (WIPO), the Global Innovation Index, calculated on the basis of 79 indicators, has declined over the past four years for Japan, the United States, China, and several other G20 countries. This decline reflects a relative improvement in their positions within the overall sample of 128 countries. Thus, under conditions of intensifying global competition among leading world economies, the role of innovation continues to grow steadily, increasingly determining national competitiveness and, ultimately, the position and role of countries in the global economic system.

In light of the above, it can be concluded that the priority and scale of public financing of innovation activities in the field of energy conservation and energy efficiency are largely determined by the degree of national governments' interest in addressing related challenges aimed, ultimately, at strengthening the energy security of their economies. This is reflected in the fact that countries pursuing active state policies in energy conservation and efficiency use public R&D funding as one of the main sources for developing innovative technologies and equipment aimed at improving energy efficiency across various sectors and activities.

Thus, these countries have identified the enhancement of national energy security as a key priority of innovation-driven development, which serves as an integrating objective at the state level. This priority provides a strong impetus for the innovative modernization of national economies and contributes to maintaining their competitiveness in the context of the emerging new technological paradigm. Therefore, international experience in implementing state policies in energy conservation and energy efficiency within the framework of innovative development should be given close attention at different levels of economic governance in Russia.

An analysis of macroeconomic indicators of developed countries shows that the most active state policies in the field of energy conservation and energy efficiency management are implemented in countries characterized, first, by a positive trend of declining energy intensity independent of structural economic changes; second, by a high level of public financial support for R&D projects in the energy and environmental sectors; and third, by a high level of energy dependence and recent measures aimed at its reduction [39]. According to the study, the United States, EU countries, Japan, and China most closely meet these criteria. The extensive experience accumulated by these countries in public administration in the field of energy conservation and the application of efficient energy-use technologies is embedded in their established regulatory and legal frameworks and is reflected in legislation, national targeted programs for energy saving, systems of standardization and certification, and related instruments [10–13].

Among the identified characteristic features of energy conservation and energy efficiency management practices across different countries, the following can be highlighted:

First, a clearly defined hierarchy of strategic and tactical managerial interventions in the field of energy conservation and energy efficiency can be observed. This hierarchy may be considered in terms of the scale and scope of transformations, the methods and nature of interventions, sectoral specificity, and time horizons of implementation. In particular, a consistent tightening of regulatory measures is evident, ranging from informational and educational initiatives to the introduction of mandatory and voluntary technical standards; from the free dissemination of information on energysaving behavior among all economic agents as general guidelines, to the adoption of binding action plans and the development of comprehensive monitoring mechanisms ensuring their implementation.

Second, there are clearly identifiable common ideological principles and structural features underlying the formation of regulatory frameworks in different countries. These relate to the structure of national legislation, procedures for its implementation, the degree of regulatory strictness, the balance between state regulation and market mechanisms, and the extent of alignment between national energy efficiency legislation and international commitments.

This is reflected in the fact that in the countries under review, a regular strategic review of national development priorities is conducted, during which the interconnections between energy conservation and energy efficiency systems and broader state strategic priorities are updated or reconfigured. This, in turn, enables the synchronization of goals and objectives across different policy domains, increases implementation efficiency through coordination, and generates additional effects through policy integration.

For example, EU legislation establishes a flexible balance between state regulation and market mechanisms, allowing member states to account for their legal and socio-economic specificities while simultaneously fulfilling their obligations. This is achieved through mechanisms for harmonizing national legislation and EU regulatory acts in the field of energy conservation and energy efficiency.

Third, there are clearly defined common features of public policy implemented by virtually all developed countries actively engaged in energy conservation and efficiency improvement, aimed at stimulating innovation processes associated with the application of new technologies and scientific breakthroughs in the energy sector.

For instance, in the United States and EU countries, the voluntary product labeling program “Energy Star” has been implemented. It is periodically revised in such a way that, upon adoption of a new standard, only about one quarter of the currently produced equipment complies with it. As a result, manufacturers seeking to remain part of the program are compelled to continuously improve their products, investing significant resources in research and development and intensifying their innovation activities.

Among the most important energy efficiency measures introduced in the United States in recent years are the following: the “Superior Energy Performance” certification program, which provides industrial enter-

prises with technological roadmaps for continuous improvement of energy efficiency while maintaining competitiveness; energy efficiency standards for the residential and utilities sector; fuel economy standards for motor vehicles; rebates for consumers purchasing energy-efficient appliances; grants to states and local authorities to support energy efficiency and conservation projects in public buildings; targeted investments in energy-saving and public transport development projects; improvement of energy efficiency in information and communication technologies; expansion of tax incentives for homeowners and businesses undertaking energy-efficient retrofits at their own expense; promotion of electricity generation based on renewable energy sources; and a range of other measures.

In the EU, measures have been adopted to stimulate technological modernization and expand demand in innovative product markets. The most important include minimum energy efficiency standards for products; CO₂ emission standards for cars and vans; regulatory measures for EU structural and investment funds; the Electricity Internal Market Directive, including provisions for smart meter deployment; and the EU Emissions Trading System.

To stimulate research and development in energy conservation and energy efficiency, the Strategic Energy Technology Plan was revised in 2013, and an energy efficiency component was introduced into the “Horizon 2020” programme, which represented the largest EU framework programme for research and innovation during the period 2014–2020. Its total budget exceeded EUR 80 billion, of which approximately 7.5% was allocated to energy-efficient technologies in construction and industry, as well as supporting technologies, including information, telecommunications, and related fields. In addition, funding procedures were simplified, thereby granting researchers greater flexibility in implementing their ideas and developing genuinely innovative technological solutions.

In several European countries (including the United Kingdom and Italy) as well as in the United States, steps have also been taken in recent years to gradually reduce the dominant position of large electricity companies in the market. To this end, new electricity generation companies employing innovative energy technologies are being progressively integrated into the energy market.

In Japan, one of the key instruments of state policy in the field of energy efficiency is a system supporting business enterprises in the implementation of innovative energy-saving technologies, as well as preferential lending for energy-saving measures provided by the Japan Development Bank

[14–16].

Legally established criteria define the requirements for companies obliged to use energy rationally in production processes, alongside guidelines for the preparation of long-term plans across various industrial sectors with regard to electricity supply, gas supply, heat supply, and industrial waste management. The tax system is continuously evolving, introducing new mechanisms to encourage investment in the restructuring of energy supply systems, and a dedicated support

framework has been established for enterprises implementing innovative energy-saving technologies. In addition, measures for technological development in this area have been defined, including research into fundamental technologies for rational energy use and the development of methods for their practical application.

In Asian industrialized countries (China, the Republic of Korea, Singapore, Hong Kong, and Taiwan), the legislative restriction of the use of certain obsolete technologies is widely practiced. For example, China has implemented a program for the closure of small-scale plants and outdated production capacities ("CSPOC"). At the same time, bans on obsolete technologies are generally accompanied by measures stimulating the dissemination of new technologies, including support for enterprises engaged in the production of new goods, the transfer and localization of innovative technologies from foreign companies, as well as budget subsidies for consumers of such products.

Thus, the analysis of leading global practices in public administration demonstrates that state policy in the field of energy conservation and energy efficiency is integrated into a country's system of strategic priorities and generates demand within the national economy for the development of advanced, including innovative, technologies and equipment. Moreover, energy conservation and energy efficiency, as a key direction of priority technological development, create an additional vector for the implementation of scientific, technical, and experimental design projects aimed at improving machinery, equipment, and technologies.

The findings obtained are supported by empirical studies conducted in developed countries. These studies substantiate the role of state support for innovation activity in the energy sector as a means of improving the energy efficiency of the economy and suggest that public policy should ensure regulated yet sufficiently flexible conditions for stimulating innovation in the energy domain. In this context, particular emphasis is placed on the synchronization of innovation and energy policies. The necessary conditions and potential effects of such synchronization at both national and supranational levels have been examined using the example of cooperation between the European Union and the United States in transforming their energy systems through technological innovation, as well as through an assessment of the impact of electricity market reforms in the United Kingdom on the innovative development of the power sector, where liberalization of the electricity market was accompanied by a decline in innovation performance until specific state support measures were introduced.

However, such studies have been conducted to a very limited extent for developing countries. Moreover, it has been found that the results of research obtained for developed economies cannot be directly generalized to developing countries.

Thus, international experience demonstrates that addressing energy conservation and energy efficiency challenges through their close integration with innovation activities yields significantly higher results compared to their independent implementation. Consequently, the interrelationship between energy efficiency policy and innovation-driven development is

becoming increasingly strong, creating broad opportunities for technological modernization of industrial production and its orientation toward advanced energy-saving technologies. In other words, countries pursuing active policies in energy conservation and energy efficiency increasingly regard the stimulation of innovation processes related to new technologies and scientific discoveries in the energy sector as one of the key priorities.

The results obtained and the conclusions drawn may serve as a basis for the development of domestic practices in managing energy conservation and energy efficiency, which is particularly relevant in the context of innovative modernization of the national economy during its transition to a new technological paradigm of development [17–19].

III. Formation of a mechanism for activating energy conservation and improving the energy efficiency of the economy.

In recent years, increasing attention has been paid at various levels of governance to improving the energy efficiency of the Azerbaijani economy. At present, the energy intensity of Azerbaijan's gross domestic product is almost four times higher than the global average and nearly seven times higher than that of leading European countries. Therefore, it is not surprising that one of the state development programs of Azerbaijan is fully devoted to various aspects of improving energy efficiency and developing the energy sector.

The results of the conducted analysis indicate that institutional conditions necessary for stimulating energy conservation and energy efficiency improvements are being developed at sectoral levels of economic governance. However, despite the measures undertaken, various aspects of activating energy conservation and energy efficiency processes have not been reflected in innovation development programs. This situation is further exacerbated by the low level of synchronization between policies in the field of energy conservation and energy efficiency and those in the field of innovation development. In practice, these represent two relatively isolated areas of activity, within which independent strategic documents are formulated, target indicators are defined, planning and implementation procedures are regulated, monitoring systems are established, and distinct organizational, informational, legal, and financial-economic support mechanisms are developed.

Therefore, without integrating the energy conservation and energy efficiency management mechanism into the innovation development system of the national economy, issues of energy saving and energy efficiency will not be regarded as a key priority of innovative modernization of the Azerbaijani economy.

To address this situation, the following conceptual model is proposed, which outlines the logical sequence of actions for forming a mechanism to activate energy conservation and improve energy efficiency as a key direction of innovation-driven economic development.

At the first stage, activities are focused on identifying factors that may influence the activation of energy conservation and energy efficiency processes in the Azerbaijani economy in the context of its innovation development. The diversity of these factors is

grouped into three categories: political, economic, and organizational-communication factors.

At the second stage, an economic assessment of the potential consequences of the influence of different factors on the activation of energy conservation and energy efficiency processes is conducted. This is necessary because the magnitude of influence of each group of factors may vary significantly. The obtained results can be used to forecast the possible impact of these processes on the outcomes of innovation-driven economic modernization.

The entire set of tasks within this stage involves modeling the influence of various activation factors on the results of innovation modernization and includes both direct and inverse forecasting problems.

Direct problems are associated with assessing changes in key economic indicators at different levels of governance as a result of the activation of energy conservation and energy efficiency processes. By modeling the dynamics of various factors, their impact on the outcomes of innovation modernization of the Azerbaijani economy can be studied in order to introduce necessary adjustments into management processes.

The second group consists of inverse problems. These are aimed at determining threshold values of the influence of identified activation factors under which target economic indicators at different levels of governance can still be achieved. Therefore, solving inverse problems is of particular importance from the perspective of active management of innovation modernization processes in the Azerbaijani economy under current development conditions.

At the third stage of the proposed model, conceptual design of possible directions for activating energy conservation and energy efficiency processes is carried out.

At the fourth stage, organizational aspects of implementing the developed activation mechanism are considered, including, first and foremost, an assessment of the readiness of managers at different levels of economic governance to address activation problems of varying complexity and scale.

At the fifth stage of the conceptual model, a comprehensive assessment is conducted of the intellectual, material, financial, organizational, administrative, and other resources required to launch the proposed activation mechanism.

The methodological framework underlying the proposed approach is based on viewing the energy sector as a complex system that, from the perspective of national economic interests, can be analyzed from two standpoints. On the one hand, it represents an independent production and technical system; on the other hand, it constitutes a key subsystem of the national economy. As a production and technical system, the energy sector is a basic industry of the Azerbaijani economy, ensuring all spheres of socio-economic activity with energy products generated through a complex set of processes involving the production, conversion, transmission, distribution, and utilization of energy resources.

Considering the domestic energy sector from this perspective, it can be stated that the goals and objectives of its functioning have not undergone significant changes compared to earlier stages of development. As

before, the primary priority remains the provision of all categories of consumers with various types of energy resources required for their activities. Therefore, from the standpoint of strategic management of energy conservation programs, the most relevant approach is normative (target-oriented) forecasting. Under this approach, specific energy-saving parameters required to achieve the desired outcomes in this field are clearly defined. The target indicator in this context is the energy intensity of the national economy [20–21].

However, even under this approach, the key issue accompanying the formation of an energy conservation strategy is transformed, first, into the justification of target indicators for different levels of governance, and second, into their transmission and implementation at each managerial level.

The first problem arises already at the stage of coordinating sectoral-level interests. From a mathematical perspective, this task is distributive in nature. Its solution consists of determining numerical values of energy conservation and energy efficiency indicators to be assigned to individual regions. Once such a solution is obtained, the issue of harmonizing regional energy-saving targets can be considered resolved.

Another important aspect should also be emphasized. The degree of influence of energy costs on gross regional product varies significantly across regions due to the factors mentioned above. Therefore, the development of strategic and program documents requires addressing two major issues.

First, it is necessary to analyze the impact of various factors on key macroeconomic indicators of regional development, including gross regional product (both in total and per capita terms), labor productivity, and related indicators. Based on such an analysis, a selective approach can be applied to setting specific energy-saving and energy efficiency targets for different regions, as well as to assessing possibilities for financial support of regional initiatives in this area.

Second, it is necessary to identify the impact of various factors on the magnitude of energy expenditures and determine the degree of their influence. For example, research results may show that the dominant influence is exerted by industrial production costs or by the level of investment in innovative technologies, etc. Based on this, regions would be able to independently determine priority areas for addressing energy efficiency challenges, with corresponding financial allocations.

The next problem in developing energy conservation and energy efficiency programs arises from the fact that a region, as an administrative-territorial unit, does not itself produce or consume resources. Production, economic, social, cultural, and other activities are carried out by enterprises, organizations, and institutions located within its territory. These entities are also the direct consumers of various types of resources, including energy.

This leads to a second coordination problem, which arises between, on the one hand, the regional level that must ensure the implementation of previously established and agreed federal indicators, and, on the other hand, individual enterprises, organizations, and institutions operating within its territory.

Thus, the task of allocating targets for achieving energy conservation and energy efficiency indicators is further extended and transferred to the next level of governance—namely, between the regional authorities and the individual economic entities operating within the region.

As a solution to this problem, the numerical values of energy conservation and energy efficiency indicators to be assigned to individual regional entities now serve as the key output parameters. Failure to ensure coordination of interests between different levels of governance, as well as the absence of a scientifically grounded justification for the feasibility of achieving the set targets, may result in the developed strategies, programs, forecasts, and other policy documents becoming purely declarative in nature, often acquiring a political rather than practical character, as was previously the case, for example, with the anticipated but unrealized doubling of national gross domestic product. In such cases, highly optimistic target benchmarks, indicators, and performance metrics may be established for the economy as a whole or its individual sectors; however, despite their apparent significance and formal robustness, they are unlikely to be achieved in practice.

Another possible approach to addressing this issue is to allocate targets not among individual enterprises, organizations, and institutions, but rather among specific projects in the field of energy conservation and energy efficiency improvement. In this case, regional authorities select on a competitive basis those projects that ensure the best performance indicators in the field of energy efficiency. Funding from the regional budget is then allocated to the selected projects. The implementation of these projects is expected to deliver the required outcomes in energy conservation.

Of particular importance in the proposed methodological framework are the organizational and economic aspects of designing and implementing the activation mechanism for energy conservation and energy efficiency, integrated into the innovation development system of the national economy. Their relevance stems from the fact that neglecting organizational issues may become a critical barrier to achieving the overall objectives of the mechanism. Among these, two aspects are of primary importance: first, the harmonization of legislation in the fields of energy conservation, energy efficiency, and innovation development; and second, the provision of adequate information support for the integration of these processes.

The harmonization of legislation in these areas may serve as one of the key factors stimulating the processes of creation, implementation, and commercialization of energy-efficient innovations.

Conclusion

At all levels of governance, the transition of the national economy to an innovation-driven development path places particular emphasis on the selection of such development priorities that can provide a strong impetus for innovative modernization and enhance competitiveness under the emerging new global technological paradigm. One of these priorities is the improvement of energy efficiency in the Azerbaijani economy. The present study is focused on addressing the challenges associated with the implementation of this priority, which

is considered a system-forming factor in the context of innovation-driven economic development. The main results obtained are as follows:

1. An assessment of the strategic development prospects of the economy under the transition to a new technological paradigm based on innovation-driven modernization was carried out. The specific features of the existing system of innovation activity organization were identified. It was established that the measures implemented by the state authorities have enabled the economy to follow a relatively balanced and well-structured trajectory of innovation development policy.

2. The causes and cyclical nature of intensified efforts to address energy conservation and energy efficiency challenges at different stages of economic development were identified. It was demonstrated that the existing model of energy efficiency management is not fully adequate to current economic conditions, thereby necessitating its further improvement and adaptation.

3. A model describing the dependence of GDP energy intensity on changes in key indicators was proposed, including the share of the service sector in the economy and the share of natural resource revenues in GDP. Simulation modeling of energy intensity dynamics under different scenarios of external political and economic conditions was conducted.

4. It was noted that a priority direction for improving energy efficiency in the national economy is the enhancement of innovation activity among domestic producers, implying an increase in innovation financing at different levels of governance. Minimum threshold values for the growth of domestic expenditures on research and development required to maintain GDP energy intensity at the 2035 level were substantiated.

5. A significant and statistically meaningful correlation between innovation activity indicators and energy efficiency indicators was confirmed, and the strength of this relationship was determined. It was substantiated that the coordination of innovation development processes and energy efficiency within a unified management framework can be considered a key direction for improving enterprise-level energy efficiency under conditions of innovation-driven economic development.

6. It was established that addressing energy conservation and energy efficiency challenges in different countries through their close integration with innovation activity yields higher results compared to their independent implementation. It was shown that the interconnection between state policies in the fields of energy efficiency and innovation development is becoming increasingly strong at different levels of national economic governance.

7. The proposed approach to the development and implementation of energy conservation and energy efficiency programs under conditions of innovation-driven development will enhance and expand the potential of energy-saving processes through their alignment with innovation processes at various levels of economic governance. It will also contribute to the development of globally competitive products and

technologies, while significantly supporting the resolution of technological lag and accelerating national economic growth.

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DIGITALIZATION OF THE OIL INDUSTRY: SCIENTIFIC ASPECTS AND JUSTIFICATION OF INTELLIGENT TECHNOLOGIES**Karimov K.***Associate Professor, Internationally Certified Economist,
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<https://doi.org/10.5281/zenodo.20186437>***Abstract**

Most onshore oil fields and offshore deposits located in the Caspian sector of Azerbaijan extend over hundreds of square kilometers. A significant proportion of these fields are situated in challenging operating environments, including high-temperature zones, deep-water areas, and reservoirs characterized by hard-to-recover reserves. These conditions, combined with the growing need to ensure technological and industrial safety, create substantial challenges for the development and operation of oil fields amid continuously increasing global demand for oil and gas. Consequently, oil enterprises require highly reliable digital infrastructure capable of ensuring enhanced operational efficiency, safety, and real-time monitoring of numerous technological devices deployed throughout the field.

In recent years, oil companies worldwide have increasingly relied on intelligent technologies for the management and operation of oil fields. These technologies have proven to be an effective instrument for improving industrial safety, increasing labor productivity, and enhancing the economic efficiency of oil production processes. Modern digital solutions optimize all stages of the operational cycle through the rapid acquisition and processing of production data using advanced analytical systems based on the Internet of Things (IoT). This approach facilitates more efficient reservoir management and improves the overall effectiveness of field development.

The experience of leading international oil companies demonstrates that the implementation of intelligent technologies produces highly reliable and economically efficient results, contributing both to improved hydrocarbon production processes and to cost reduction across individual technological operations.

Keywords: digital industry; intelligent technologies; Internet of Things; robotization; artificial intelligence; digital twins; oil fields

I. Introduction

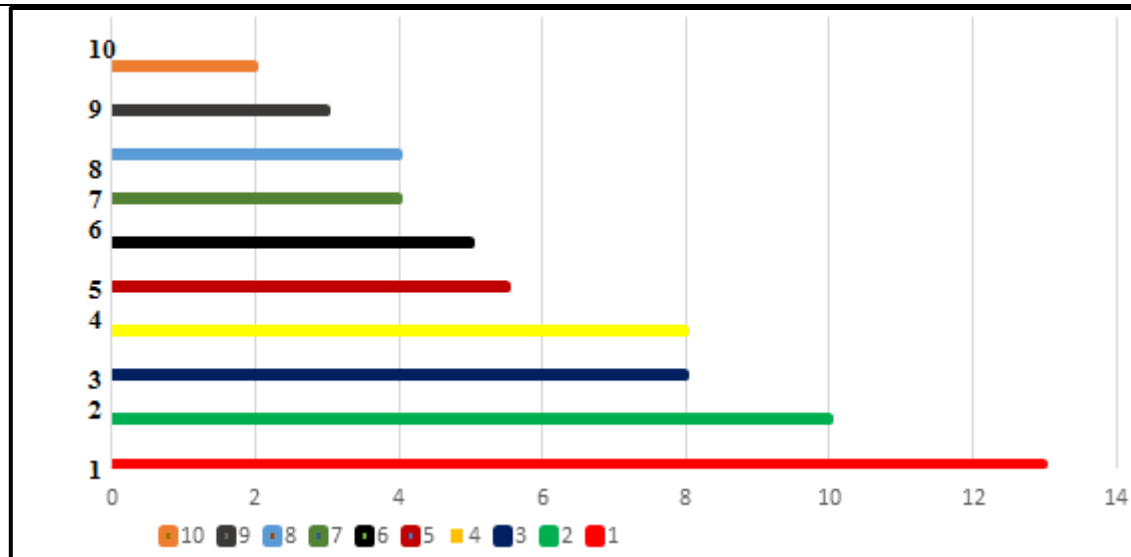
Given the continuous growth in global demand for energy resources and the necessity of developing oil fields characterized by hard-to-recover reserves, as well as fields at the final stage of production, oil companies increasingly require more efficient oil recovery technologies based on fundamentally new approaches and principles.

The terms “*new production technologies*” or “*advanced manufacturing technologies*” generally refer to technologies and technological processes, as well as machines, equipment, devices, and instruments based on microelectronics or controlled by computer systems

and utilized in the design, production, processing, and distribution of industrial products.

In Azerbaijan and internationally, technologies are considered innovative if they are fundamentally new, developed for the first time, and have no domestic or foreign analogues. In addition, such technologies possess qualitatively advanced characteristics that meet or exceed current technological standards and industrial requirements. These technologies are typically based on breakthrough or highly efficient pioneering inventions.

Expert assessments conducted in the United States regarding the most significant advanced manufacturing technologies are presented in Fig. 1.



1 — measurement and precision sensing technologies; 2 — nanomanufacturing; 3 — information technologies; 4 — nanomaterials; 5 — adaptive control systems; 6 — biomanufacturing; 7 — biofuels; 8 — mobile robotics; 9 — technical response systems; 10 — high-efficiency industrial heat recovery technologies.

Figure 1. Significance of Advanced Manufacturing Technologies (U.S. Expert Assessments)

As illustrated in Fig. 1, advanced manufacturing technologies constitute the primary driving force behind the emergence of new markets and the further development of the digital economy. These technologies also represent the technological foundation of the ongoing digital revolution. Among them, intelligent technologies occupy a central position [1-4].

According to Daniel Bell, the new technological paradigm assigns a decisive role to electronic systems for information processing, storage, transmission, and digital transformation. In his view, the implementation of intelligent technologies in industrial production should encompass the following components:

- management control loops, ranging from operational and routine control to strategic and situational management;
- management domains, including financial, labor, production, logistics, customer, and supplier management;
- functional subsystems of the corporate management system;
- management levels, including corporations, subsidiaries, and structural divisions;
- management objectives aimed at reducing production, financial, environmental, and other operational risks and costs, while increasing the reliability and efficiency of industrial systems;
- professional roles and workplaces of employees.

At the same time, intelligent technologies enable the effective transformation of scientific knowledge generated within higher education institutions into a direct productive force of the economy.

Currently, the key technological trends associated with the modern industrial revolution, commonly referred to as Industry 4.0, include:

- the Internet of Things (IoT);
- machine-to-machine (M2M) communications;
- modeling and forecasting based on advanced analytics and big data technologies;
- cloud and fog computing, as well as distributed data storage systems;
- industrial robotization;
- additive manufacturing;
- cognitive technologies;
- advanced human-machine interfaces;
- computer simulation of equipment, materials, and technological processes;
- augmented reality technologies;
- intelligent sensors;
- 3D printing technologies.

The emergence of the global Internet network in 1982 marked the beginning of a fundamentally new virtual environment encompassing digital communication platforms, banking transactions, online commerce, social networks, computer games, and numerous other forms of human activity. As a result, a new integrated model of human interaction has evolved, combining both physical and virtual environments.

This transformation has contributed to the formation of a fundamentally new digital model of global economic development, characterized by the deep integration of information technologies into all spheres of social and industrial activity (Figure 2).

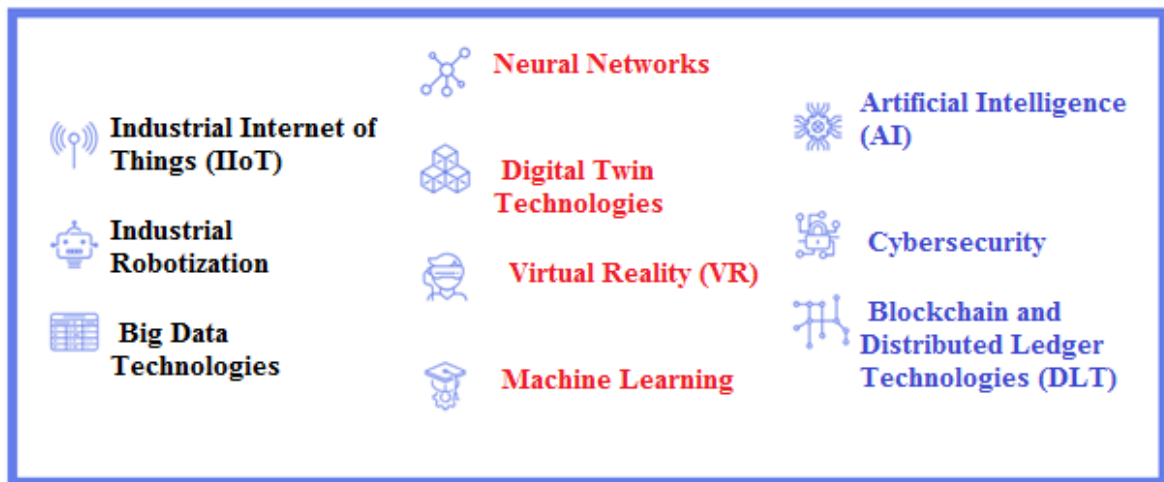


Figure 2. Key Innovative Methods and Technologies in the Modern Oil Industry

In particular, the first Internet-connected device appeared in 1990, when John Romkey introduced a unique toaster that could be remotely controlled via the global network.

Today, the Internet of Things (IoT) is understood as the practical implementation of a network of inter-connected physical objects equipped with embedded electronic devices that enable effective interaction with each other and with the external environment. This concept minimizes the need for direct human involvement in a wide range of operations and processes, thereby

fundamentally transforming economic and social systems [5-9].

The concept and the term *Internet of Things* were first proposed in 1999 by Kevin Ashton, head of the Auto-ID research group at the Massachusetts Institute of Technology. However, according to analysts from Cisco, the actual emergence of the IoT era dates back to 2008–2009, when the number of devices connected to the global network exceeded the world's population for the first time (Figure 3). At this stage, the "Internet of People" evolved into the "Internet of Thing

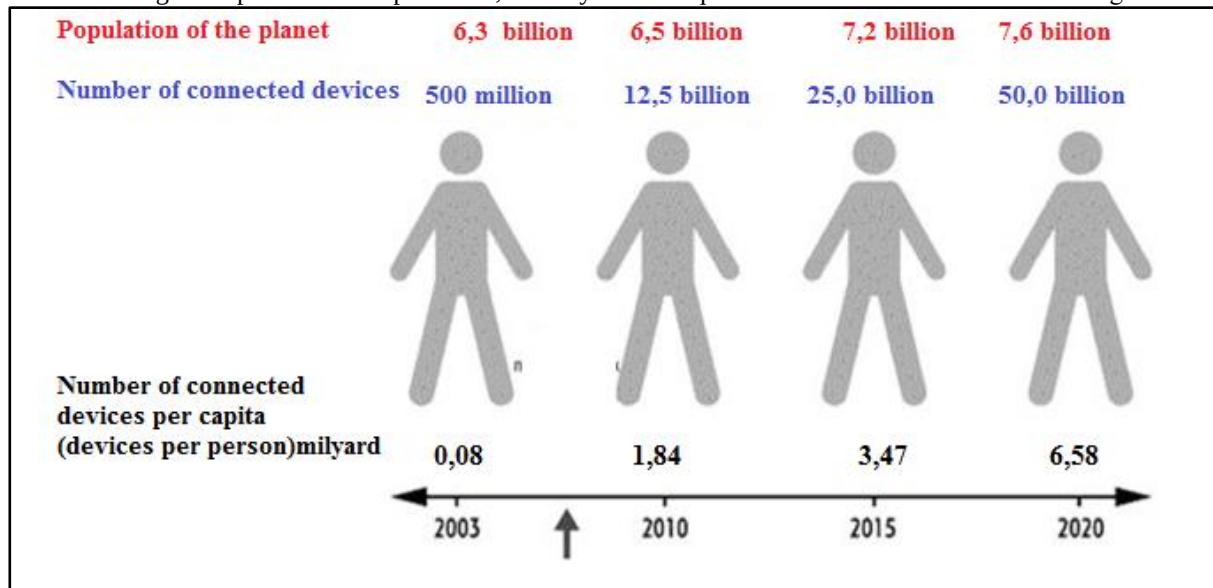


Figure 3. Trends in World Population Growth and the Number of Connected Devices

At present, more than 20 billion diverse devices are already connected to the Internet of Things. On average, there are approximately three connected electronic devices per person worldwide. These typically include smartphones, laptops, and various smart devices such as smartwatches, fitness trackers, connected televisions, or intelligent security systems.

As a result of this large-scale interconnection, the global system already comprises over 2 billion connections among approximately 200 million different devices, and it is projected that this number will reach 28 billion connections by 2030 [10-12].

The real-world IoT ecosystem consists of three main segments, each evolving along its own trajectory:

1. Machine-to-Machine (M2M) communications;
2. Smart systems, where widespread adoption begins with peripheral devices connected via Bluetooth and similar protocols;

3. Context-aware (situational) IoT, comprising traditional household devices enhanced with advanced digital capabilities.

Currently, several key trends characterize the development of Machine-to-Machine communication technologies:

♦ Remote nodes are becoming increasingly intelligent, with most devices expected to gain significantly expanded functionality in the near future.

♦ Miniaturization of M2M systems is enabling their application in domains previously considered impractical or infeasible.

♦ High reliability, operational readiness, and system stability are essential features, as many systems operate autonomously without human intervention and are often deployed in remote or inaccessible environments where maintenance is costly or technically challenging.

♦ High-speed bidirectional data transmission is a critical requirement, as data are frequently generated by mobile devices and subsequently transmitted for processing and analysis.

II. Some Aspects of the Application of Digital Technologies in the Oil Industry of Azerbaijan

The adoption of digital technologies in the oil and gas sector is driven by the continuous efforts of companies to improve operational efficiency and optimize oil and gas production processes. In this context, diverse production-related information has become a key strategic resource for the management of modern industrial systems, while the level of information technology development significantly determines the competitiveness of oil fields, pipelines, and other production facilities.

Since 2011, the concept of the Fourth Industrial Revolution has been widely introduced into professional discourse. It is defined as the transition toward fully automated digital production systems equipped with intelligent real-time control mechanisms, capable of continuous interaction with the external environment. This paradigm extends beyond individual enterprises and envisions the integration of production systems into a global industrial network for goods and services.

The main drivers of the ongoing digital revolution include the widespread dissemination of computing technologies—primarily personal computers—the ubiquitous expansion of the Internet, and the mass adoption of portable digital communication devices.

As a result, the digital revolution has led to the global transition toward a digital economy, the principles of which are embedded in the conceptual framework of Industry 4.0.

Thus, modern digital society has emerged as a result of the widespread development of mobile services, the Internet, and digital broadcasting, which in turn are based on advances in semiconductors, telecommunications, display technologies, and other fields of information and communication technologies.

The previous industrial paradigm (Industry 3.0) was primarily based on the automation of individual production processes, whereas Industry 4.0 is characterized by the end-to-end digitalization of all physical assets within an enterprise and their integration into a unified digital ecosystem.

Within this framework, Industry 4.0 encompasses the digitalization and integration of the entire product lifecycle, from design and development to logistics, operation, maintenance, and service processes. Accordingly, each manufactured product is expected to have a

digital representation, meaning that all related information—including design documentation, production technologies, operational guidelines, maintenance procedures, and disposal instructions—must be digitized and made accessible to both humans and machine systems.

It is also essential that data on all ongoing processes, production stages, components, assemblies, and final products be available in real time to authorized users within a unified digital network. Industry 4.0 requires continuous data exchange among all participants involved in the production chain, including enterprise specialists, equipment, ERP systems, robots, and products.

To ensure this integration, production systems combine hardware components, technological equipment, and logistics systems into a unified cyber-physical environment. A critical element of this architecture is the continuous exchange of production data among all components of the system, enabled by Internet of Things technologies [13-14].

In addition, it should be emphasized that digital oil and gas technologies rely on extremely large volumes of heterogeneous data, commonly referred to as Big Oil Data (BOD). Globally, approximately 2.5 exabytes (10^{18} bytes) of new data are generated daily, of which the oil and gas sector accounts for up to 10%. Moreover, approximately four-fifths of this information—including seismic, geophysical, production, financial, and reporting data—exists in unstructured form.

Under these conditions, cloud computing has become one of the most efficient technologies for data storage and processing. Cloud storage refers to an online data infrastructure in which large-scale industrial datasets are distributed across multiple network-connected servers provided as a service to users. Logically, these resources operate as a single virtualized computing environment, while physically the servers may be geographically distributed across different continents.

Such an architecture enables real-time exchange of production data among authorized participants, significantly improving the quality and speed of managerial decision-making. This, in turn, reduces operational downtime and substantially decreases the likelihood of industrial accidents. In the oil and gas industry, cloud technologies have become a core component of digital infrastructure, primarily aimed at reducing IT-related costs, while also serving as a key enabler for unlocking additional value from advanced digital solutions. As a result, companies with access to accurate and real-time data demonstrate an average annual improvement of approximately 24% in the speed and quality of production decision-making.

As a result, major oil companies worldwide are increasingly adopting digital and intelligent technologies. For example, Shell and TotalEnergies utilize robotic systems, while Chevron and Shell employ drones for inspection and monitoring tasks. Equinor uses 3D visualization technologies, and Chevron applies video analytics to detect pipeline leaks. In addition, BP is implementing large-scale projects on offshore production platforms based on the Industrial Internet of Things (IIoT).

Furthermore, most global oil and gas companies already integrate artificial intelligence, as well as virtual and augmented reality technologies, into industrial operations. In 2018, BP joined the Enterprise Ethereum Alliance, which focuses on the adoption of smart contracts in corporate systems. Even blockchain technology has gained significant attention within the oil industry.

Currently, various oil companies implement proprietary initiatives that can be classified as “smart” or “intelligent manufacturing” projects:

- ♦ “Smart wells” – Smart Wells (Schlumberger);
 - ♦ “Smart operations” – Smart Operations (Petro);
 - ♦ “Integrated operations” – Integrated Operations (Equinor, OLF);
 - ♦ “Electronic operations management” – eOperations (North Hydro);
 - ♦ “Real-time operations management” – Real Time Operations (Halliburton);
 - ♦ “Correct drilling direction” – eDrift (OD);
 - ♦ “Integrated Asset Operation Model” – IAOM (ADCO);
 - ♦ “Smart field” – Smart Field (Shell);
 - ♦ “Intelligent field” – i-Field (Chevron);
 - ♦ “Field of the Future” – Field of the Future (BP);
 - ♦ “Digital Oil Field of the Future” – DOFF (CERA);
- “Intelligent field optimization and remote management” – INFORM (Cap Gemini) and others. Конечной формы

All these systems are largely similar in terms of their core objectives and operational tasks. They are designed to simulate, with a high degree of reliability, various scenarios in oil and gas production systems and to enable the selection of optimal decision-making strategies, including more efficient utilization of highly qualified personnel within the company [15–18].

The presence of “intelligence” in any complex system—whether biological (human) or engineering-based (such as wells, oil fields, pipelines, etc.)—implies the capability of autonomous regulation and optimization of multiple internal operational parameters in response to diverse and continuously changing environmental conditions or external influences.

This necessitates the implementation of so-called intelligent technologies in the oil industry. Their primary purpose is to maximize the productivity of an expanding well stock, reduce operational expenditures, and accelerate hydrocarbon production while increasing overall output.

In this context, an intelligent technology in an oil field is understood as an automated control system for oil and gas production operations that ensures continuous optimization of an integrated reservoir model as well as an efficient production management model.

The most promising intelligent oil and gas technologies include drilling, monitoring, and maintenance robotics, low-temperature reservoir treatment technologies, subsea oil production systems, automated (unmanned) platforms, and wireless control systems (Figure 4).

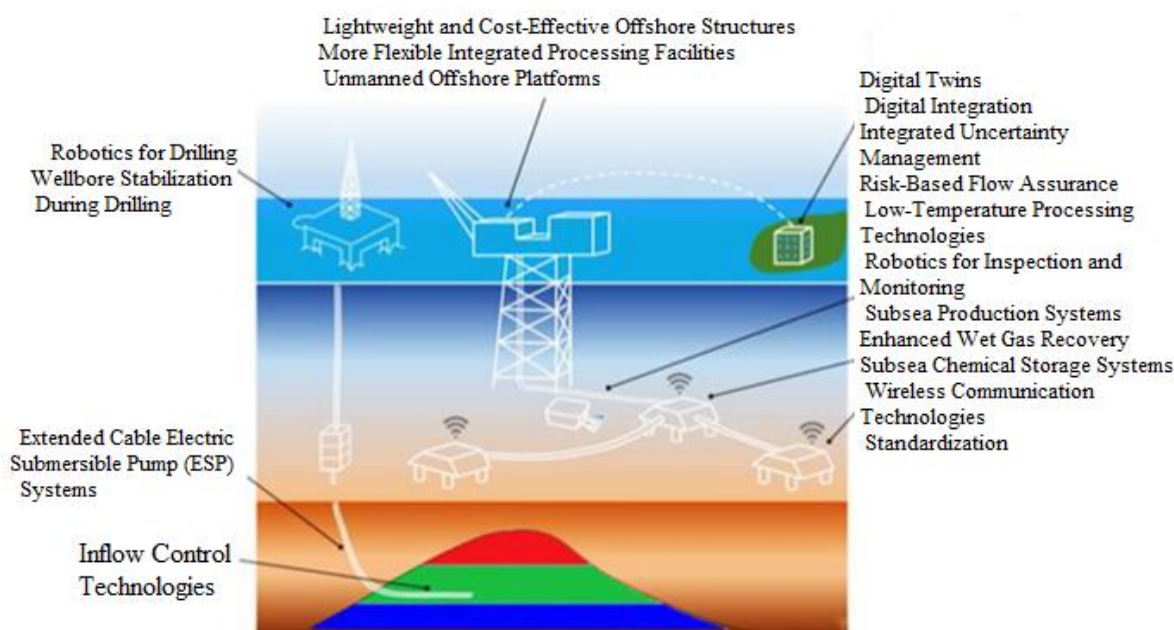


Figure 4. Key Elements of Offshore Oil Production Digitalization

III. Effects of Intelligent Oilfield Technologies

In our view, the use of real-time production data enables digital oil and gas companies to achieve the following objectives:

- expansion of the enterprise resource base;
- increased hydrocarbon recovery rates and oil production volumes;

- reduction in the number of operational incidents, including leaks and emissions;
- improved operational efficiency and enhanced personnel safety;
- optimization of operational activities in oil and gas production, transportation, and processing, as well as across drilling and refining facilities operating in both stationary and field environments.

The principal indicators determining the economic feasibility of expenditures associated with oilfield development, as well as the implementation and operation of intelligent technologies, include [19-24].

- annual economic effect;
- profit growth;
- payback period of capital investments.

Table 1.

Indicators	Advantages of Intelligent Technologies		
	Field Management Technologies		
	Conventional Automated Technologies (Active Management)	Digital Technologies (Reactive Management)	Intelligent Technologies (Proactive Management)
Increase in Oil Production, %	1,0	4,0	10,0
Increase in Oil Reserves, billion tons	5,0	10,0	15,0
Increase in Oil Recovery Factor (ORF), %	1,0	5,0	10,0
Specific Automation Costs, % of Revenue or per tons	0,5	1,0 – 2,0	2,0 - 4,0
Reduction in Unit Oil Production Costs, %	2,0	5,0	15,0
Labor Productivity Growth, %	1,0	5,0	10,0

It should be noted that, according to expert assessments, the widespread implementation of intelligent technologies could increase the global oil recovery rate

from 30% to 50%. According to estimates by Saudi Aramco, the introduction of reservoir nanorobots at mature oilfields could increase the oil recovery factor to 60–70%.

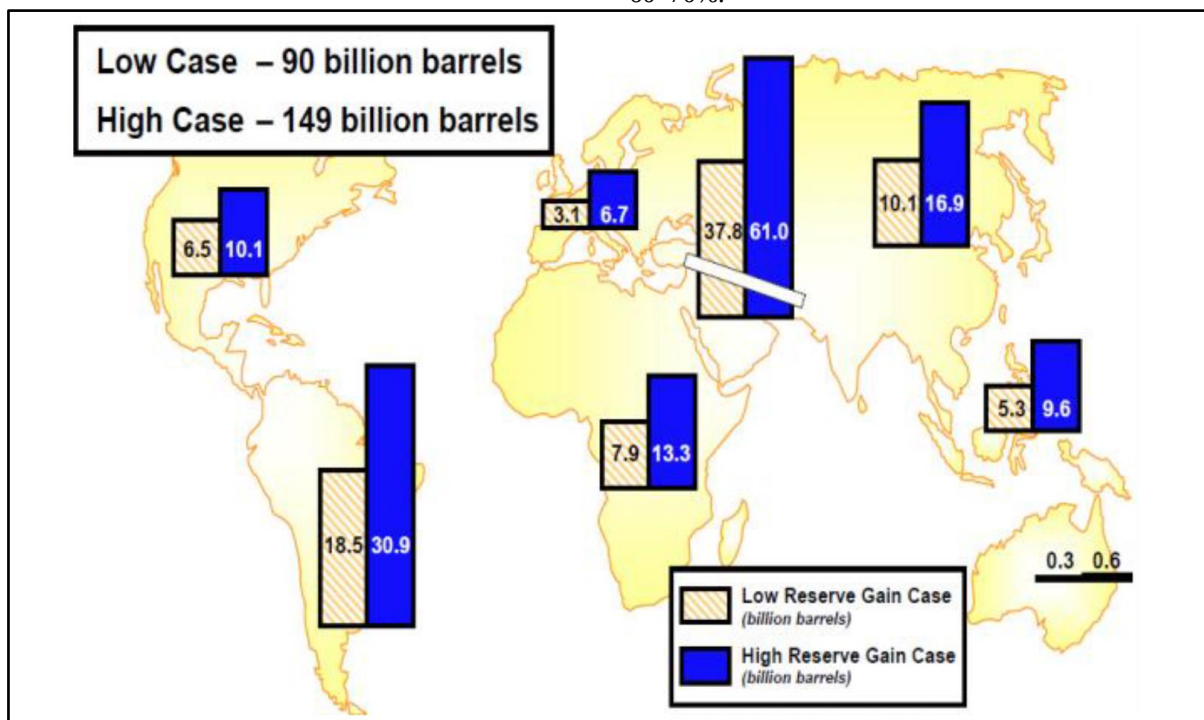


Figure 5. Increase in Hydrocarbon Reserves by World Regions Resulting from the Implementation of Intelligent Technologies (Source: IHS Inc.)

According to estimates by Cambridge Energy Research Associates (CERA), the comprehensive utilization of intelligent oilfield technologies may improve field development efficiency by approximately 2–7%, reduce oil recovery costs by nearly 25%, and increase the productivity growth rate of oil and gas operations by 2–4%.

The economic efficiency of intelligent oil and gas production can be achieved through increased oil and gas output, primarily as a result of:

- reducing downtime in oil production wells;
- minimizing losses of oil, gas, and water through optimized separation, dehydration, desalination processes, and early leak detection within hydrocarbon gathering systems;

•comprehensive optimization of oil production processes.

In particular, within the framework of intelligent oilfield implementation in California operations, field operators can access real-time operational data on tablets while conducting inspections or remaining inside their vehicles, as well as receive alerts regarding situations requiring immediate response. This approach enables personnel to avoid multiple daily visits to each well and instead focus on wells requiring maintenance.

Conclusion

The foundation of the Fourth Industrial (“digital”) revolution lies in the processes of economic digitalization, which are leading to radical transformations across entire industries. For example, the widespread adoption of Internet telephony, various messaging platforms, and virtual operators has driven a fundamental restructuring of business models within telecommunications companies. Similarly, the emergence of autonomous and electric vehicles, as well as the development of car-sharing services, is significantly reshaping the traditional structure of the transport sector.

Alongside the expansion of shale resource production, the growing use of renewable energy sources, and the activities of numerous start-ups, these innovations have also had a substantial impact on the oil and gas industry.

It is essential to effectively leverage these still largely untapped opportunities. From a technological perspective, Azerbaijan’s offshore oil and gas sector is already well prepared for large-scale digital transformation. It has accumulated a significant volume of production data, established the necessary computational infrastructure for data processing, and benefits from continuously decreasing costs of innovation implementation, as well as an expanding body of practical experience in their application.

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COMPARATIVE ANALYSIS OF THE EFFECTIVENESS OF INTERNAL AND EXTERNAL FINANCIAL CONTROL IN A MARKET ECONOMY ENVIRONMENT

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Abstract

In the context of modern market relations, the effectiveness of financial control mechanisms plays a significant role in ensuring financial discipline, transparency, and sustainable economic development. Internal and external financial control systems serve as essential instruments for monitoring financial operations, preventing fraud, and improving the efficiency of resource allocation. The purpose of this study is to conduct a comparative analysis of the effectiveness of internal and external financial control in a market economy environment and identify key directions for their improvement.

The research applies comparative analysis, systematic approach, and analytical evaluation methods to examine the functional characteristics, advantages, and limitations of both internal and external financial control systems. The study investigates their institutional roles in ensuring compliance with financial regulations, minimizing financial risks, and strengthening corporate governance mechanisms.

The findings reveal that internal financial control provides operational flexibility and continuous monitoring within organizations, while external financial control ensures independent assessment and enhances public trust through objective evaluation. Despite their different functional approaches, both systems are interdependent and contribute to improving financial accountability. The study identifies digital transformation, regulatory modernization, and integration of automated monitoring systems as major directions for increasing the effectiveness of financial control.

The practical significance of the research lies in developing recommendations for strengthening financial control systems in market economies, particularly in developing countries, including Azerbaijan.

Keywords: financial control, internal financial control, external financial control, market economy, financial efficiency, audit, financial transparency, corporate governance

1. Introduction

The development of modern market economies has significantly increased the importance of effective financial control systems in ensuring transparency, accountability, and efficient allocation of financial resources. Financial control has become one of the most critical components of sustainable economic governance due to growing market competition, globalization processes, and increasing complexity of financial transactions (Arens et al., 2022).

The transition toward market-based economic systems requires enterprises and public institutions to develop stronger financial supervision mechanisms. As market relations deepen, organizations face growing pressure to improve financial discipline, reduce operational risks, and ensure compliance with both national and international financial regulations (Messier et al., 2021).

Internal financial control plays an essential role in preventing operational inefficiencies, identifying accounting irregularities, and supporting managerial decision-making. According to COSO (2017), internal control systems help organizations achieve strategic goals through risk assessment, control activities, and effective monitoring mechanisms.

External financial control ensures independent oversight of financial activities conducted by enterprises and public institutions. Independent audits, governmental inspections, tax supervision, and regulatory reviews help improve investor confidence and strengthen corporate accountability (Hayes et al., 2020).

The rapid development of digital technologies has fundamentally transformed traditional financial control mechanisms. Artificial intelligence, blockchain systems, big data analytics, and automated accounting platforms create new opportunities for improving monitoring systems while simultaneously generating additional regulatory challenges (Appelbaum et al., 2021; Vasarhelyi et al., 2018).

Recent studies emphasize that sustainable economic development increasingly depends on effective strategic management and institutional adaptation mechanisms. Kerimova et al. (2024) highlight that properly constructed strategic systems significantly influence market development processes, especially in innovative economic environments. This perspective demonstrates that financial control systems must also adapt to rapidly changing market conditions.

Corporate fraud scandals, financial crises, and institutional weaknesses continue to expose deficiencies

in traditional control systems. Events such as Enron, Wirecard, and global banking failures demonstrate the urgent need for modernization of both internal and external financial control systems (Coffee, 2005).

For developing economies such as Azerbaijan, strengthening financial control systems remains especially relevant due to economic diversification goals, increasing foreign investments, and public sector reforms. Modern financial supervision mechanisms contribute directly to national economic security and institutional sustainability (World Bank, 2023).

Despite extensive studies in auditing and financial management, limited research has comparatively evaluated the effectiveness of internal and external financial control systems in market economies. This study aims to fill this research gap by analyzing comparative efficiency and identifying future development directions.

The primary objectives of the study include:

- examining theoretical foundations of financial control;
- comparing internal and external control mechanisms;
- identifying current institutional problems;
- proposing modernization strategies for improving efficiency.

Despite the extensive body of literature on auditing, corporate governance, and financial supervision, limited studies have conducted a comprehensive comparative assessment of internal and external financial control effectiveness under modern market economy conditions, particularly in developing and transition economies.

This research seeks to address this gap by examining the comparative strengths and weaknesses of both financial control mechanisms and evaluating their role in improving financial transparency, institutional accountability, and economic sustainability.

The scientific novelty of the study lies in integrating traditional financial control theories with contemporary digital transformation trends, including automation, artificial intelligence, and modern risk management approaches.

The practical significance of the research is determined by the development of recommendations aimed at improving financial control systems in enterprises and public institutions operating in competitive market environments.

The article is structured as follows: the next section reviews relevant literature, followed by methodology, comparative analysis, discussion of findings, and concluding recommendations.

2. Literature Review

Financial control has long been considered one of the fundamental mechanisms for ensuring economic stability, preventing financial misconduct, and improving institutional efficiency. The concept has evolved significantly from traditional inspection-based approaches toward modern risk-oriented and technology-driven control systems.

Early theoretical approaches to financial control primarily focused on compliance verification and fraud

prevention. According to Simons (1995), control systems were initially developed as mechanisms for monitoring organizational behavior and ensuring adherence to established financial procedures. Traditional financial control models emphasized accounting verification, document examination, and legal compliance.

Agency theory significantly contributed to the development of financial control research. Jensen and Meckling (1976) argued that conflicts between owners and managers create information asymmetry, increasing the need for effective financial monitoring systems. Internal financial control mechanisms emerged as essential tools for reducing agency costs and minimizing managerial opportunistic behavior.

Internal financial control has received considerable attention in corporate governance literature. COSO (2017) identifies five major components of internal control systems:

- control environment
- risk assessment
- control activities
- information and communication
- monitoring activities

These components form the foundation of modern enterprise-level financial supervision systems.

Studies by Kaplan and Norton (2008) emphasize that internal controls directly influence organizational performance by improving operational efficiency and strategic decision-making. Effective internal control systems allow firms to detect irregularities at earlier stages and reduce financial losses.

External financial control has traditionally focused on independent verification of financial reporting. Arens et al. (2022) state that external auditing enhances transparency by providing objective assessments for investors, governments, and other stakeholders.

Hayes et al. (2020) emphasize that external financial control plays an essential role in protecting public interests by increasing confidence in financial statements and reducing the risks of financial manipulation.

The collapse of major corporations such as Enron, Lehman Brothers, and Wirecard significantly intensified academic interest in financial control failures. Coffee (2005) argued that weak external oversight mechanisms often contribute to large-scale corporate scandals.

Technological transformation has created a new research direction in financial control literature. Vasarhelyi et al. (2018) highlight that big data analytics has significantly improved audit efficiency and fraud detection capabilities.

Similarly, Appelbaum et al. (2021) argue that artificial intelligence and blockchain technologies are transforming both internal and external financial control systems by automating repetitive procedures and improving real-time monitoring.

In public sector financial management, OECD (2023) emphasizes that effective external control institutions improve fiscal discipline and reduce corruption risks in developing economies.

The World Bank (2023) reports that countries with stronger financial oversight institutions demonstrate

higher levels of investor confidence and macroeconomic stability.

Recent research conducted by Kerimova et al. (2024) emphasizes the growing importance of strategic adaptability in modern market systems. Their findings indicate that institutions operating in rapidly changing economic environments must continuously modernize governance mechanisms to maintain competitiveness and sustainability. This approach is also highly relevant for financial control systems.

Despite the broad literature on auditing, corporate governance, and financial supervision, several important research gaps remain:

- limited comparative studies between internal and external financial control systems
- insufficient focus on transition economies
- lack of integration between traditional control models and digital technologies
- limited practical recommendations for institutional modernization

This study contributes to the literature by addressing these gaps through a comparative analysis of internal and external financial control effectiveness in modern market economies.

3. Research Methodology

The methodological basis of this study is formed by a comprehensive analytical framework aimed at assessing the comparative effectiveness of internal and external financial control systems in market economy conditions. Since financial control mechanisms operate within complex institutional, technological, and regulatory environments, a multidimensional research design was selected.

The study applies qualitative, comparative, analytical, and system-based research methods to examine the operational characteristics of financial control systems. The methodology allows for identifying both theoretical and practical differences between internal and external financial supervision mechanisms.

The research process consists of several consecutive stages:

- identification of theoretical approaches to financial control;
- analysis of international scientific literature;
- examination of institutional financial control models;
- comparative assessment of internal and external financial control mechanisms;
- identification of modernization factors affecting financial supervision systems;
- development of practical recommendations.

To ensure objectivity, the study uses secondary data obtained from:

- scientific articles indexed in Scopus and Web of Science;
- reports of OECD;
- World Bank analytical materials;
- International Monetary Fund reports;
- International Federation of Accountants documents;
- national financial legislation and audit regulations.

3.1 Comparative analysis method

Comparative analysis serves as the primary research method in this study. This method enables the evaluation of internal and external financial control according to several performance indicators.

The main comparison criteria include:

- operational flexibility
- level of independence
- risk prevention capacity
- financial transparency
- implementation cost
- regulatory compliance
- fraud detection efficiency
- adaptability to digital transformation

Table 1.

Comparative characteristics of internal and external financial control

Evaluation criteria	Internal financial control	External financial control
Operational speed	High	Moderate
Independence	Low	High
Continuous monitoring	High	Low
Fraud prevention	Moderate	High
Regulatory compliance	Moderate	High
Cost efficiency	High	Moderate
Stakeholder trust	Moderate	High
Digital adaptability	High	Moderate

As shown in Table 1, internal control demonstrates stronger operational flexibility, while external control provides higher levels of independence and public trust.

3.2 System analysis method

The system analysis method was applied to examine financial control as an integrated institutional mechanism involving multiple stakeholders. Financial control system participants include:



Figure 1. Institutional Structure of Financial Control Participants

This approach helps identify interdependencies among financial institutions and control mechanisms.

3.3 Content analysis method

Content analysis was used to examine international financial regulations and institutional frameworks affecting financial control systems.

The following documents were analyzed:

- International Standards on Auditing (ISA)
- COSO Internal Control Framework
- OECD financial governance reports
- IMF accountability reports
- Azerbaijani financial legislation
- corporate governance standards

This analysis helped identify regulatory gaps and modernization needs in financial control systems.

3.4 Statistical analysis

The study incorporates international statistical indicators related to financial transparency and audit effectiveness.

The following indicators were reviewed:

- corruption perception index
- financial transparency index
- public accountability index
- audit efficiency indicators
- institutional trust indicators

According to World Bank (2023) reports, countries with stronger financial control institutions demonstrate higher fiscal stability and lower corruption risks.

3.5 Digital transformation model in financial control

Technological development has become an important methodological variable in this study.

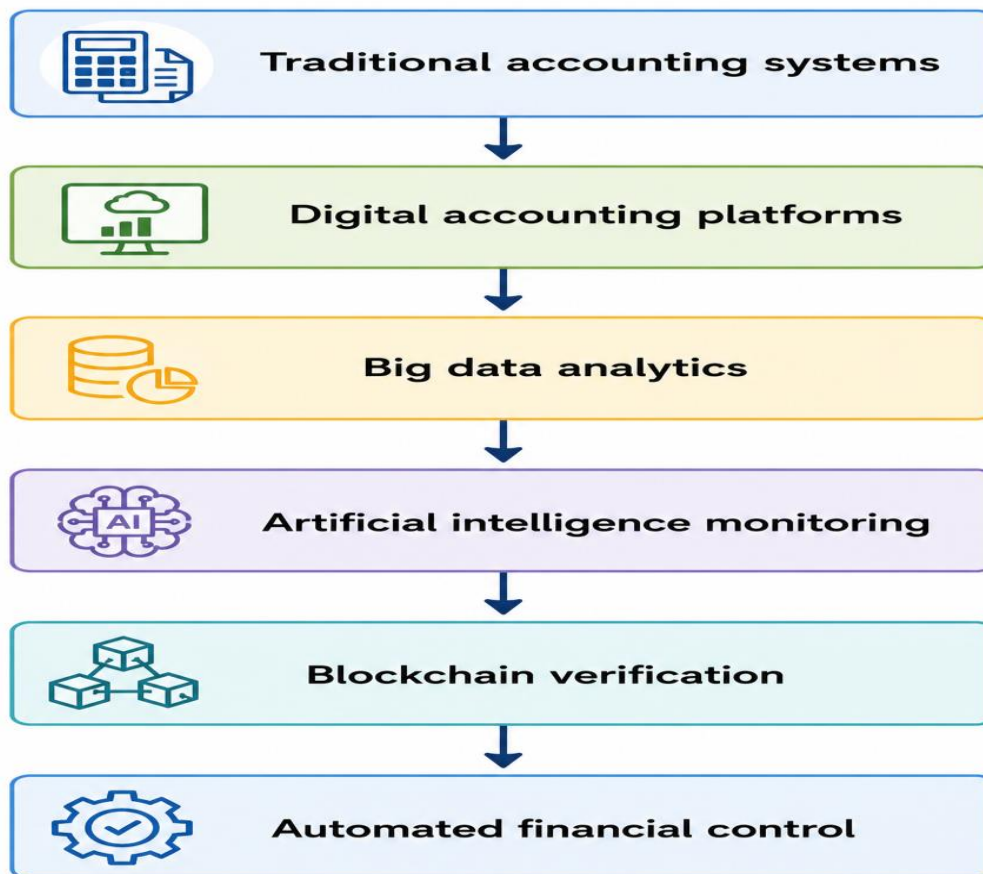


Figure 2. Digital Transformation Model of Financial Control

This model demonstrates the transformation of financial control systems under modern market conditions.

Research Hypothesis

The study tests the following hypothesis:

H1: Effective integration of internal and external financial control systems improves financial transparency, reduces institutional risks, and increases economic efficiency.

Research limitations

The research is primarily based on secondary sources and comparative analysis. The absence of primary survey data may limit empirical generalization; however, the use of international institutional databases improves reliability.

The selected methodology provides a strong basis for evaluating financial control systems and supports further empirical analysis in the next section.

4. Results and Discussion

The comparative analysis conducted in this study demonstrates that both internal and external financial control systems play critical roles in ensuring financial discipline within market economies. However, their operational efficiency varies depending on institutional structures, technological capacity, regulatory frameworks, and organizational objectives.

The findings indicate that internal financial control provides continuous monitoring of financial transactions and allows organizations to identify operational risks at early stages. Internal control systems are more

flexible and adaptive because they operate within enterprises and allow immediate intervention when irregularities occur.

Large corporations increasingly rely on internal audit departments to monitor financial transactions, assess risk exposure, and improve managerial decision-making processes. Effective internal financial control contributes to:

- reducing operational losses
- improving financial reporting quality
- strengthening corporate governance
- preventing internal fraud
- increasing managerial accountability

Despite these advantages, internal financial control often faces challenges related to limited independence. Since internal auditors operate within the same organization, managerial pressure may affect objectivity.

External financial control demonstrates stronger independence and higher public credibility. External audits, tax inspections, state financial supervision authorities, and regulatory agencies provide objective evaluations of financial activities.

The findings show that external financial control significantly contributes to:

- increasing investor confidence
- ensuring legal compliance
- reducing financial manipulation
- improving public trust
- strengthening institutional accountability

However, external control mechanisms may face delays due to bureaucratic procedures, periodic audits, and high implementation costs.

Table 2.

Major problems of internal and external financial control systems

Problems	Internal control	External control
Limited independence	High	Low
Bureaucratic delays	Low	High
High operational cost	Low	Moderate
Fraud detection delays	Moderate	Moderate
Technological adaptation problems	Moderate	High
Regulatory pressure	Moderate	High

Table 2 demonstrates that both systems face different institutional challenges. Internal control struggles with independence, while external control experiences higher bureaucratic barriers.

The study also reveals that digital transformation significantly improves both control mechanisms. Artificial intelligence systems allow real-time risk detection, while blockchain technologies improve transaction transparency.

Countries implementing automated financial monitoring systems demonstrate:

- lower corruption levels

- faster fraud detection
- higher tax compliance
- stronger investor confidence

According to OECD (2023), countries with advanced digital financial control systems report significantly higher efficiency levels compared to traditional control models.

For Azerbaijan and similar developing economies, modernization of financial control systems remains a strategic priority. Public financial reforms should focus on integrating internal and external control systems through digital infrastructure development.

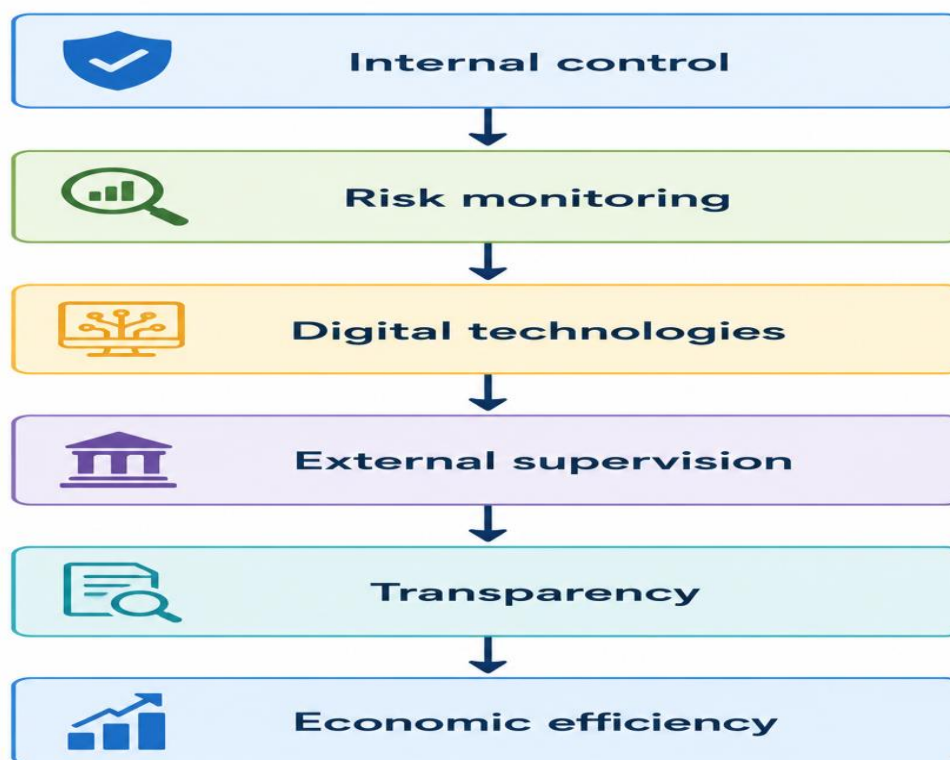


Figure 3. Integrated model of effective financial control

The results confirm that neither internal nor external financial control can independently ensure maximum financial efficiency. The most effective approach is the integration of both mechanisms supported by modern technological solutions and regulatory reforms.

5. Conclusion

The study examined the comparative effectiveness of internal and external financial control systems under

modern market economy conditions. The research confirmed that financial control plays a crucial role in ensuring financial discipline, institutional transparency, and sustainable economic development.

The findings demonstrate that internal financial control provides continuous operational monitoring, rapid response mechanisms, and greater flexibility in managing financial risks within organizations. Internal

control systems help enterprises detect accounting irregularities at early stages, reduce operational losses, and improve managerial decision-making processes.

At the same time, external financial control ensures higher levels of independence, objectivity, and public trust. External audits, regulatory supervision, and governmental inspections strengthen financial accountability and improve compliance with legal and institutional requirements.

The comparative analysis revealed that neither internal nor external financial control systems can independently ensure maximum financial efficiency. Internal control systems often face challenges related to limited independence, while external control systems may experience bureaucratic delays and higher operational costs.

The study confirmed the research hypothesis that the effective integration of internal and external financial control mechanisms significantly improves financial transparency, reduces institutional risks, and increases economic efficiency.

One of the major findings of the study is the growing role of digital transformation in financial control modernization. Artificial intelligence technologies, blockchain verification systems, big data analytics, and automated auditing platforms are becoming essential tools for improving financial supervision efficiency.

For developing economies such as Azerbaijan, modernization of financial control systems should become one of the strategic priorities of economic reforms. Strengthening institutional cooperation between enterprises, audit institutions, and government regulators can improve financial stability and investment attractiveness.

Based on the research findings, the following recommendations are proposed:

- strengthen internal audit departments within enterprises
- improve independence of external financial control institutions
- accelerate digital transformation of financial supervision systems
- modernize financial legislation
- expand professional training in digital auditing technologies
- improve coordination between internal and external control institutions

The practical significance of the study lies in its recommendations for policymakers, financial institutions, corporate managers, and researchers working on financial governance issues.

Future research may focus on empirical analysis of financial control efficiency in specific sectors of the economy and cross-country comparative studies.

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THE ROLE OF LOCAL GOVERNMENT IN ENSURING DEMOCRATIC GOVERNANCE: A CONSTITUTIONAL AND LEGAL ANALYSIS

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РОЛЬ МЕСТНОЙ ВЛАСТИ В ОБЕСПЕЧЕНИИ ДЕМОКРАТИЧЕСКОГО УПРАВЛЕНИЯ: КОНСТИТУЦИОННО-ПРАВОВОЙ АНАЛИЗ

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Abstract

This article examines the constitutional development of local government in the Republic of Tajikistan. It examines the role of local government bodies in the development of a democratic state. It examines the system of local government bodies, their legal status, organization, and activities.

Аннотация

В статье рассматривается конституционное развитие местной власти в Республике Таджикистан. Рассматривается роль местных органов государственной власти в развитие демократического государства. Исследуются система органов местной власти, их правовое положение, организация и деятельность.

Keywords: Constitution, state, local government, local government bodies, local self-government, Majlis of People's Deputies, Chairman.

Ключевые слова: Конституция, государство, местная власть, местные органы государственной власти, местное самоуправление, Маджлиси народных депутатов, Председатель.

Каждое демократическое государство, провозгласившее права и свободы человека высшей ценностью, не может нормально функционировать без развитой системы местных органов государственной власти. Местная власть является одним из составных частей демократического государства, развитого гражданского общества. В то же время, именно местное управление дает импульс развитию демократических институтов, давая возможность гражданам участвовать в жизнедеятельности государства.

Система, организация и деятельность местных органов государственной власти во всех странах так или иначе имеют конституционную основу. В федеративных государствах ограничиваются установлением общих принципов и основ организации и деятельности местных органов государственной власти. Правда, с выбором демократического пути развития, в конституционной практике большинства государств предпочтение отдается местному самоуправлению. В настоящую систему, наряду с органами территориального общественного самоуправления, включаются и представительные, исполнительные и распорядительные органы власти. При этом в определении назначения местной государственной власти предпочтение отдается в зависимости от различных ориентиров то местному управлению и самоуправлению, то исполнительной власти или местной государственной администрации или же территориальному самоуправлению.[8]

При определении нового статуса местной власти новые государства, образовавшиеся после распада СССР стали каждый исходить из своего представления о местном самоуправлении и местной государственной власти. **Некоторые** из них бесповоротно утвердили у себя систему местного самоуправления. При этом сочли, что народ суверенен и власть принадлежит ему, и народ формируя органы местного самоуправления, всю полноту власти сосредотачивает в своих руках. В известной мере, автономно от центральных органов государственной власти осуществляют управление местной жизнью. **Другие**, признавая и утверждая систему местного самоуправления, в то же время не отказались от существования местных представительных и исполнительных органов государственной власти. Они полноправно участвуют на своей территории в осуществлении государственной власти. **Третьи**, не смогли отказаться от устоявшейся системы местной представительной и исполнительной власти, местное самоуправление ограничили пределами первого территориального уровня, т. е. в поселке и селе. [9] К последнему относится законодательство Республики Таджикистан, статья 78 Конституции, которая провозгласила, что органом самоуправления поселка и села является джамоат.[1]

При выборе той или иной системы местной государственной власти стран Центральной Азии наряду с новым пониманием сущности и предназначения местной власти, также исходили из традиционного понимания сочетания роли и значения

местного самоуправления. На первичном уровне преобладает решение проблем местного значения через органы местного самоуправления, а на среднем или базовом и областном уровне через представительные и исполнительные органы государственной власти. По существу Кенгаши народных депутатов (Республика Узбекистан), местные Кенешы (Республика Кыргызстан), местные Маслихаты (Республика Казахстан), местные Маджлисы народных депутатов (Республика Таджикистан) и халк маслихати (Республика Туркменистан) являются прототипами Советов народных депутатов и являются местными представительными органами государственной власти. Исключением является местный представительный орган государственной власти – халк маслихати в Республике Туркменистан, который независимо от местной исполнительной власти и хякима самостоятельно осуществляет свою деятельность. Однако, конституционно-правовой статус настоящих представительных органов принципиально изменился и теперь местные исполнительные органы государственной власти не находятся при местном представительном органе государственной власти, а функционируют параллельно, дополняя друг друга. Возглавляет их единоличный руководитель (раис, аким, хоким, хяким), назначаемый и освобождаемый от должности Президентом республики и ответственным перед ним. Правда, местному представительному органу государственной власти предоставлены отдельные рычаги воздействия на единоличного руководителя, однако, это не столь серьёзно может воздействовать на его деятельность.

Конституционные основы организации и деятельности местных органов государственной власти, в том числе областных Маджлисов народных депутатов закреплены в главе шестой Конституции Республики Таджикистан, которая названа «Местные органы государственной власти и самоуправления» [1]. В ней определено предназначение местной власти и основные направления ее деятельности. Проведено разграничение двух ветвей местной власти – представительной и исполнительной, которые действуют в пределах своих полномочий. Они функционируют в масштабе соответствующей области, города и района. Сельский район и город выступают пространственным пределом организации и деятельности местных органов государственной власти. На низовом, первичном уровне в поселках и селах действуют органы самоуправления – Джамоаты.[4]

Республика Таджикистан состоит из Горно-Бадахшанской автономной области, областей, городов, районов, поселков и сел [1, ст.7]. Вместе с тем, административно-территориальное устройство республики не имеет единую стройную систему, т.е. она носит незавершенный характер. Значительная часть территории республики состоит из территории областей, а часть территории организована в города и районы. Областное звено местной власти возглавляет систему местной власти только в определенной части республики. Это обстоятельство по нашим наблюдениям, связано не с какими-то идеологическими или организационными установками,

а объективно вытекает из сложного географического расположения территории республики, состоящего преимущественно из горных, предгорных частей и долин. Та часть территории, которая состоит из городского и районного деления охватывает довольно протяженные территории Гиссарской и Каратегинской долины. Настоящую территорию объединить в одну административную область практически представляется весьма затруднительным. Неоднократная предыдущая практика организации областей на настоящей территории (Гиссарской, Гармской, Сталинабадской и Каратегинской), не имела надлежащего эффекта и практически не оправдывала себя. В настоящее время городские и районные органы власти, расположенные на настоящей территории непосредственно подчиняются высшим органам государственной власти республики.

Конституция определяет основное предназначение местной власти в лице представительной и исполнительной власти. Они обеспечивают исполнение Конституции, законов, совместных постановлений Маджлиси милли и Маджлиси намояндагон, постановлений Маджлиси милли, постановлений Маджлиси намояндагон, правовых актов Президента и Правительства Республики Таджикистан.

Конституция Республики Таджикистан 1994 ввела новую систему местных органов государственной власти и отменила старую систему местной государственной власти, основанной на полномочии Советов народных депутатов [12, 253]. Органом местной представительной власти в областях, городах и районах провозгласила Маджлисы народных депутатов, которыми руководит председатель. Срок полномочий Маджлиса народных депутатов определен 5 лет. Между старой и новой системой местной представительной власти есть определенные сходства: в их названии, в порядке избрания, в формах деятельности. Есть сходства в представительном характере их организации и деятельности. Однако между ними много существенных различий [10,368].

Прежде всего, различие заключается в идеологических предпосылках их организации и деятельности. Советы народных депутатов служили организационно-правовой формой власти трудящихся и их деятельность соответствовала политическим установкам руководящих органов коммунистической партии. Статус депутатов Советов основывался на императивном мандате и во все своей деятельности депутат оставался подотчетным и ответственным перед избирателями и их организацией. Уровень реализации наказов избирателей служил мерилем эффективности деятельности депутатов, вплоть до досрочного отзыва депутата не справившегося с выполнением наказа.

Маджлисы народных депутатов осуществляют представительную форму государственной власти на местах. Согласно Конституции Республики Таджикистан идеология ни одной партии, общественного и религиозного объединения, движения или группы не может быть признана как государственная [3,11]. И хотя, Маджлисы народных депутатов

избираются в условиях многопартийности, и их состав отражает многопартийную структуру общества, однако, по конституции деятельность Маджлиса не может быть приспособлена к отражению идеологии определенной правящей или иной партии или движения.

В отличие от депутата местных Советов, депутат местного Маджлиса народных депутатов вправе свободно выражать свое мнение и голосовать в соответствии со своими убеждениями. Настоящая норма означает признание принципа свободного мандата и по новому определению статуса депутата местного Маджлиса народных депутатов. Однако, на наш взгляд, свободный мандат депутата местного Маджлиса не является абсолютным и не означает полную независимость депутата от избирателей и общественных объединений, поддержавших его кандидатуру в депутаты. В соответствии с Законом Республики Таджикистан «О правовом статусе народных депутатов Маджлиса народных депутатов Горно-Бадахшанской автономной области, областей, города Душанбе, городов и районов», «депутат не реже двух раз в год обязан отчитываться перед избирателями округа о своей работе, о ходе выполнения предвыборной программы» [3]. Это обстоятельство с одной стороны означает известную независимость депутата в определении своей позиции при участии в работе местного Маджлиса, с другой стороны, он должен учесть объективные интересы и пожелания своих избирателей.

Новая модель местной государственной власти - это соединение представительной и исполнительной власти под единым началом, которым руководит Председатель области, города и района. Конституционный закон Республики Таджикистан «О местных органах государственной власти» [2] внес ясность в ряд понятий, касающихся местной власти. Прежде всего, определил местный представительный орган государственной власти – Маджлисом народных депутатов Горно-Бадахшанской автономной области, областей, города Душанбе, городов и районов, который избирается избирателями соответствующих административно-территориальных единиц и в пределах своих полномочий решает вопросы местного значения. В соответствии с настоящей нормой в ст. 8 Конституционного закона подробно перечислены полномочия Маджлиса народных депутатов, которые дают им возможность осуществить государственное руководство местной жизнью.

Основными целями реформы местной власти, проводимых в годы независимости Таджикистана являются:

- децентрализация управления с целью удовлетворения нужд населения;
- упразднение власти Советов и переход к системе Маджлисов народных депутатов;
- четкое определение роли центров территориального управления;
- разделение функций представительных и исполнительных органов на каждом уровне управления, наряду с поддержкой их взаимодействия и подотчетности;

- разработка механизмов разрешения конфликтов без ущемления интересов различных уровней власти [6, 158].

В процессе конституционного и законодательного оформления института местной в Таджикистане определена система основных демократических институтов, реорганизована система местных органов государственной власти [7,144] (была сформирована трехступенчатая система местного управления: область, город и район, поселок и кишлак); были установлены новые принципы организации и деятельности органов государственной власти на местах. Иначе говоря, сформирована правовая база становления и деятельности местной власти.

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MATHEMATICAL SCIENCES

MATHEMATICAL MODELING ONE PROBLEMS FROM ECOLOGY

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Abstract

In this work, a particular ecologically significant problem is analytically described using differential equations and contemporary computer method are used to implement the solution.

Keywords: differential equations, mathematical modeling, Newton's law of cooling, numerical methods.

It should be mentioned, that Newton's law of cooling is offered as a useful tool for simulating ecological and biological issues. The problem under consideration is applied to a specific situation: the object's temperature change over time is modeled in order to ascertain when a gazelle carcass discovered in the forest was slain [1],[2].

Consider the following situation:

While walking through a nature reserve, a ranger sees the body of a dead gazelle. Upon examination, it becomes clear that the gazelle was shot by a poacher with a well-aimed shot. Two people are detained nearby, but to determine who committed the crime, it is necessary to determine when the animal was killed.

This problem can be solved using Newton's law of cooling. According to this law, the rate of cooling of an object in air is proportional to the difference in temperature between the object and the air, i.e.

$$\frac{dy}{dt} = -k(y - a), y(0) = y_0. \quad (1)$$

Here y is the temperature of the body at time t , a is the air temperature, and k is the proportionality coefficient, y_0 is the temperature of the body at time $t = 0$. The solution to the problem depends on the study of the solution to the equation. It should be taken into account that the air temperature may not change after the gazelle is killed, but it may change over time. In the first case, the solution to the equation is as follows:

$$\ln \frac{y-a}{y_0-a} = -kt, y \neq a, \quad (2)$$

If we fix the moment $t = 0$, when the unknown persons were detained, the gazelle's body temperature was $y = 31^\circ C$, and an hour later, $y = 29^\circ C$, we can determine the time of firing if we know that the gazelle's body temperature at the moment of firing was $y = 37^\circ C$ and the air temperature was $a = 21^\circ C$. Taking into account the given, we get from the last expression:

$$k = \ln \frac{31-21}{29-21} = \ln 1,25 \approx 0,223 \quad (3)$$

If we substitute (3) for k into (2) and take into account, that $y = 37^\circ C$, we get

$$t = -\frac{1}{0,223} \ln \frac{37-31}{31-21} = -\frac{1}{0,223} \ln 1,6 \approx -2,106,$$

That is, 2 hours and 6 minutes had passed from the moment the shooting began until the moment the unknown persons were detained. Note that in the considered situation, the air temperature does not change

Consider another situation:

When the air temperature changes over time, the cooling law of the body is expressed by a linear non-homogeneous differential equation:

$$\frac{dy}{dt} + ky = kb(t), \quad (4)$$

where $b(t)$ is the air temperature at time t .

Let us assume that the temperature of the gazelle's body at the time the suspects was detained was $30^\circ C$. It is also known that on the day of the incident, the air temperature dropped by $1^\circ C$ every hour in the afternoon and was $0^\circ C$ when the body was found. Let us assume that one hour after the body was found, its temperature was $25^\circ C$ and the air temperature was $-1^\circ C$. Suppose that the moment of the shooting was $t = 0$ and that the gazelle's body temperature at that moment was $y_0 = 37^\circ C$. If the time of the discovery of the killed gazelle is $t = t_1$, then $b(t) = t_1 - t$.

It is known that (4) is a linear non-homogeneous equation. If we apply the method of variation of a constant, the solution of equation (1) will be as follows:

$$y = \left(y_0 - t - \frac{1}{k}\right) e^{-kt} + t_1 - t + \frac{1}{k} \quad (5)$$

Taking into account, that at $t = t_1$ initial temperature is $y_0 = 30^\circ C$ and at $t = 1 + t_1$ $y_0 = 25^\circ C$ (5) bərabərliyindən aşağıdakı münasibətləri alırıq:

$$\begin{aligned} \left(37 - t_1 - \frac{1}{k}\right) e^{-kt} + \frac{1}{k} &= 30, \\ \left(37 - t_1 - \frac{1}{k}\right) e^{-k(t_1+1)} + \frac{1}{k} &= 26. \end{aligned}$$

From the last two equations we obtain a transcendental equation with respect to k :

$$\left(30 - \frac{1}{k}\right) e^{-k} - 26 + \frac{1}{k} = 0 \quad (6)$$

This type of equation cannot be solved by algebraic methods, so we apply one of the numerical methods, Newton's successive approximation method, to solve equation (6). For this, we reduce equation (6) to the following form:

$$30k - 1 + (1 - 26k)e^k = 0, \quad (7)$$

The last equation has the form:

$$(ak + b)e^{ak} + ck + d = 0. \quad (8)$$

In our case : $a = -26$, $b = 1$, $c = 30$, $a = 1$, $d = -1$.

Based on the results obtained, it was determined that the gazelle was killed approximately 1 hour and 12 minutes before its body was found. [1].

Using Python Programming Tools in the Analytical Solution of the Model

The Python programming language was used to more efficiently and accurately analyze the mathematical expression of the model [3]. The model, constructed based on the specified parameters, took into account the dynamics of temperature changes, and appropriate solution methods were applied for both constant and variable environmental conditions. The Python libraries numpy, math, and matplotlib were used to perform calculations, graphically represent functions, and find roots. In addition to the analytical solution of the model, numerical approaches were also implemented using the software codes presented in the study. In particular, the roots of the functions were determined using classical numerical methods, such as the bisection method, ensuring the reliability of the results.

Thus, the mathematical expression of the model was practically implemented using the specified software, and the obtained results were analyzed from both theoretical and applied perspectives.

```
import math
import numpy as np
import matplotlib.pyplot as plt

# =====
# The main parameters in the article
# =====

# Under constant air temperature conditions
T_body_initial = 37.0
T_air_const = 21.0
T_found_const = 31.0
T_found_1h_const = 29.0

# In conditions of varying air temperature
T_found_var = 30.0
T_found_1h_var = 25.0

# =====
# Auxiliary functions
# =====

def bisection(func, a, b, tol=1e-10, max_iter=300):
    fa = func(a)
    fb = func(b)

    if fa == 0:
        return a
    if fb == 0:
        return b
    if fa * fb > 0:
        raise ValueError("No root has been isolated in the interval.")

    for _ in range(max_iter):
        m = 0.5 * (a + b)
        fm = func(m)
```

```
    if abs(fm) < tol or 0.5 * (b - a) < tol:
        return m

    if fa * fm <= 0:
        b = m
        fb = fm
    else:
        a = m
        fa = fm
    return 0.5 * (a + b)

def find_bracket(func, x_min=0.01, x_max=3.0, n=20000):
    xs = np.linspace(x_min, x_max, n)
    vals = [func(x) for x in xs]

    for i in range(len(xs) - 1):
        if vals[i] == 0:
            return xs[i], xs[i]
        if vals[i] * vals[i + 1] < 0:
            return xs[i], xs[i + 1]

    raise ValueError("No interval was found for the root.")

# =====
# Under constant temperature conditions
# =====

k_const = math.log((T_found_const - T_air_const) / (T_found_1h_const - T_air_const))

t_death_relative_to_found = -(1 / k_const) * math.log(
    (T_body_initial - T_air_const) / (T_found_const - T_air_const)
)

def T_const_relative_to_found(t):
    return T_air_const + (T_found_const - T_air_const) * np.exp(-k_const * t)

elapsed_const = abs(t_death_relative_to_found)

# =====
# Under varying temperature conditions
# =====

def f_k_var(k, T_found=T_found_var, T_found_1h=T_found_1h_var):
    return (T_found - 1.0 / k) * math.exp(-k) - (T_found_1h + 1.0) + 1.0 / k

a_k, b_k = find_bracket(lambda x: f_k_var(x), x_min=0.01, x_max=2.0)
k_var = bisection(lambda x: f_k_var(x), a_k, b_k)

def g_t1_var(t1, k, T_found=T_found_var):
    return (37.0 - t1 - 1.0 / k) * math.exp(-k * t1) + 1.0 / k - T_found

a_t1, b_t1 = find_bracket(lambda x: g_t1_var(x, k_var), x_min=0.01, x_max=10.0)
```

```
t1_var = bisection(lambda x: g_t1_var(x, k_var),
a_t1, b_t1)
```

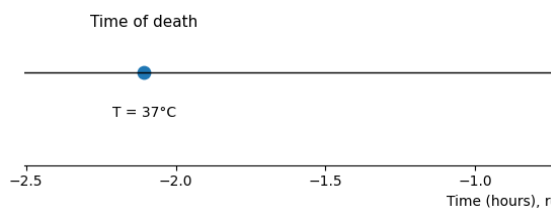
```
def T_air_var(t, t1=t1_var):
    return t1 - t
```

```
def T_body_var(t, t1=t1_var, k=k_var):
    return t1 - t + 1.0 / k + (37.0 - t1 - 1.0 / k) *
np.exp(-k * t)
```

```
print("The time of death under constant condi-
tions:", round(elapsed_const, 3), "hours")
```

```
print("The time of death under varying condi-
tions:", round(t1_var, 3), "hours")
```

Figure 1. Timeline of the



```
fig, ax = plt.subplots(figsize=(12, 2.8))
```

```
x1 = t_death_relative_to_found
```

```
x2 = 0
```

```
x3 = 1
```

```
ax.axhline(0, color='black', linewidth=1)
```

```
ax.scatter([x1, x2, x3], [0, 0, 0], s=80)
```

```
ax.text(x1, 0.12, "Time of death", ha="center",
fontsize=11)
ax.text(x2, 0.12, "Time of discovery", ha="cen-
ter", fontsize=11)
ax.text(x3, 0.12, "1 hour later", ha="center", font-
size=11)
```

```
ax.text(x1, -0.12, "T = 37°C", ha="center", font-
size=10)
```

```
ax.text(x2, -0.12, "T = 31°C", ha="center", font-
size=10)
```

```
ax.text(x3, -0.12, "T = 29°C", ha="center", font-
size=10)
```

```
ax.set_title("Figure1. Timeline of the Event and
Temperature Measurements ")
```

```
ax.set_xlim(x1 - 0.4, 1.4)
```

```
ax.set_ylim(-0.25, 0.25)
```

```
ax.set_yticks([])
```

```
ax.set_xlabel("Time (hours), relative to the time of
discovery")
```

```
for spine in ["left", "right", "top"]:
```

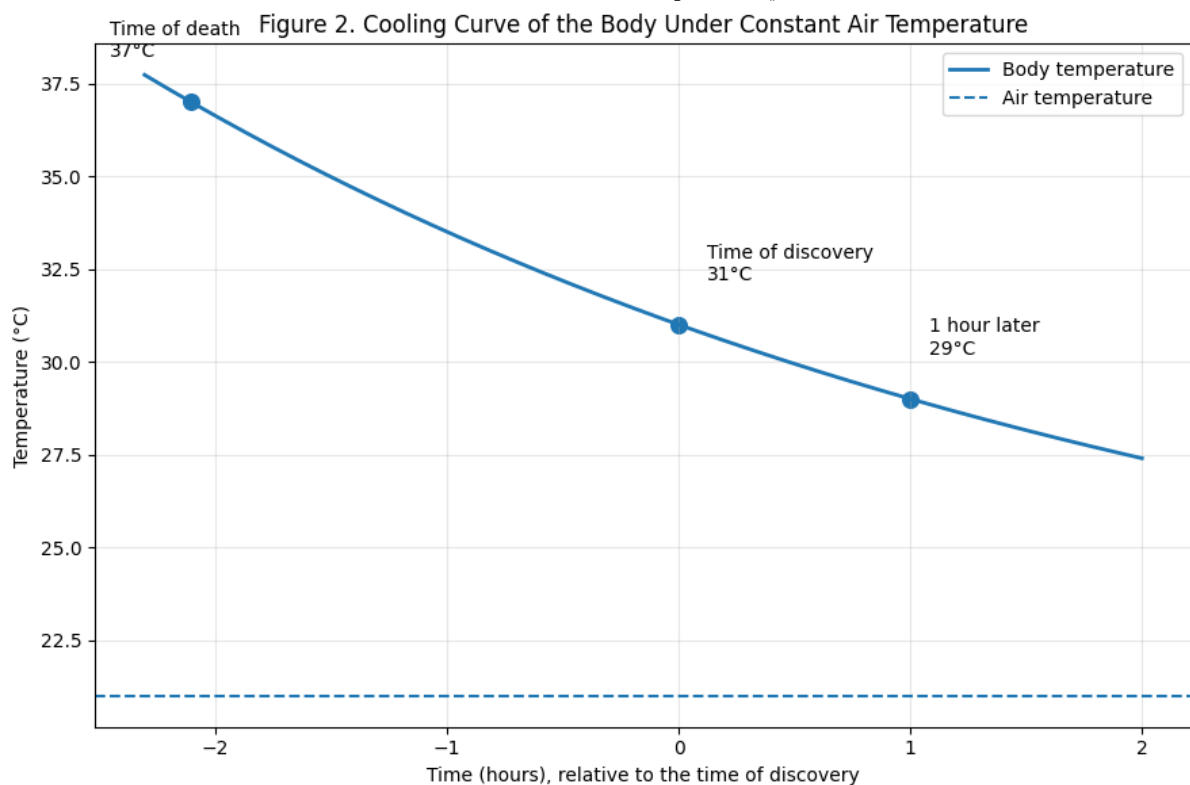
```
ax.spines[spine].set_visible(False)
```

```
plt.tight_layout()
```

```
plt.savefig("fig1_timeline.png", dpi=300,
bbox_inches="tight")
```

```
plt.show()
```

```
plt.close()
```



```
t_const = np.linspace(t_death_relative_to_found -
0.2, 2.0, 500)
```

```
T_const_vals = T_const_rela-
tive_to_found(t_const)
```

```
ax.plot(t_const, T_const_vals, linewidth=2, lab-
el="Body temperature ")
```

```
ax.axhline(T_air_const, linestyle="--", lin-
ewidth=1.5, label=" Air temperature ")
```

```
fig, ax = plt.subplots(figsize=(9, 6))
```

```
ax.scatter(
[t_death_relative_to_found, 0, 1],
```

```

[T_body_initial,
T_found_1h_const],
s=70
)

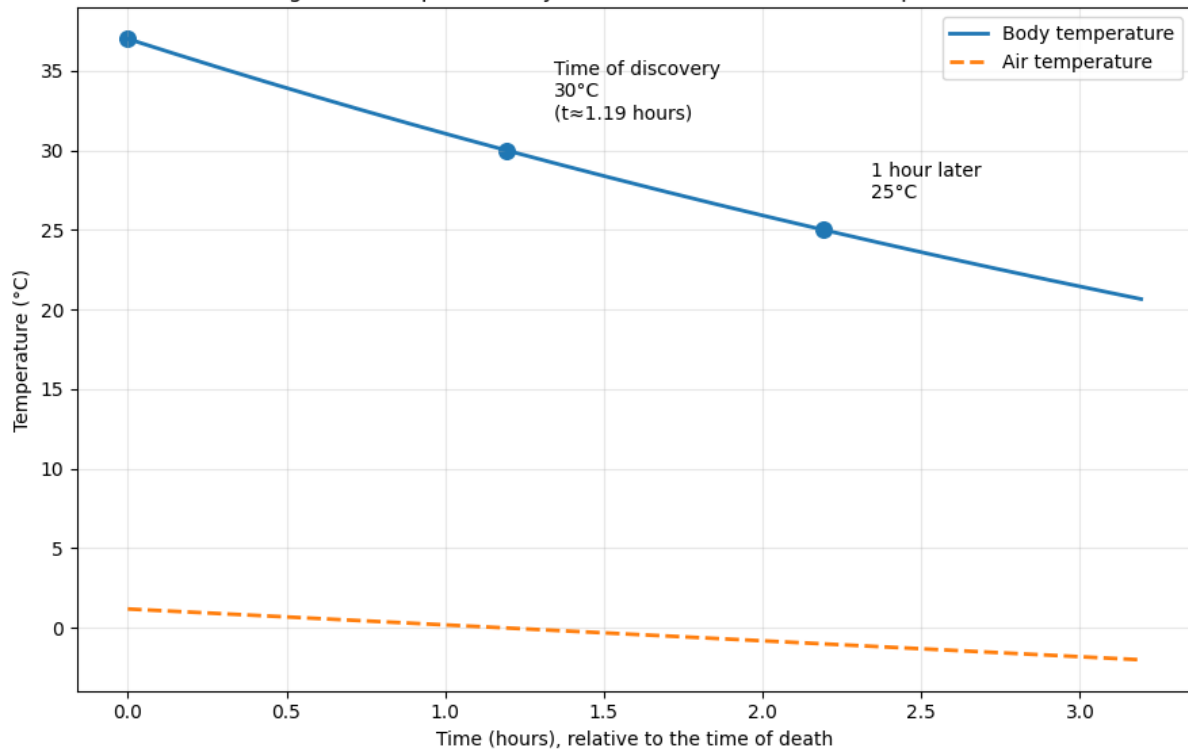
ax.text(t_death_relative_to_found - 0.35,
T_body_initial + 1.2, " Time of death \n37°C", font-
size=10)
ax.text(0.12, T_found_const + 1.2, " Time of dis-
covery \n31°C", fontsize=10)
ax.text(1.08, T_found_1h_const + 1.2, "1 hour
later \n29°C", fontsize=10)

ax.set_title("Figure 2. Cooling Curve of the Body
Under Constant Air Temperature")
ax.set_xlabel("Time (hours), relative to the time of
discovery ")
ax.set_ylabel("Temperature (°C)")
ax.grid(True, alpha=0.3)
ax.legend()

plt.tight_layout()
plt.savefig("fig2_constant_cooling.png",
dpi=300, bbox_inches="tight")
plt.show()
plt.close()

```

Figure 3. Temperature Dynamics Under Variable Air Temperature



```

t_var = np.linspace(0, t1_var + 2.0, 600)
T_air_vals = T_air_var(t_var)
T_body_vals = T_body_var(t_var)

fig, ax = plt.subplots(figsize=(9, 6))

ax.plot(t_var, T_body_vals, linewidth=2, label="
Body temperature ")
ax.plot(t_var, T_air_vals, linestyle="--", lin-
ewidth=2, label=" Air temperature ")

ax.scatter([0, t1_var, t1_var + 1], [37.0,
T_found_var, T_found_1h_var], s=70)

ax.text(0.15, 38.2, " Time of death \n37°C", font-
size=10)
ax.text(t1_var + 0.15, T_found_var + 2.0, f" Time
of discovery \n30°C\n(t≈{t1_var:.2f} saat)", font-
size=10)

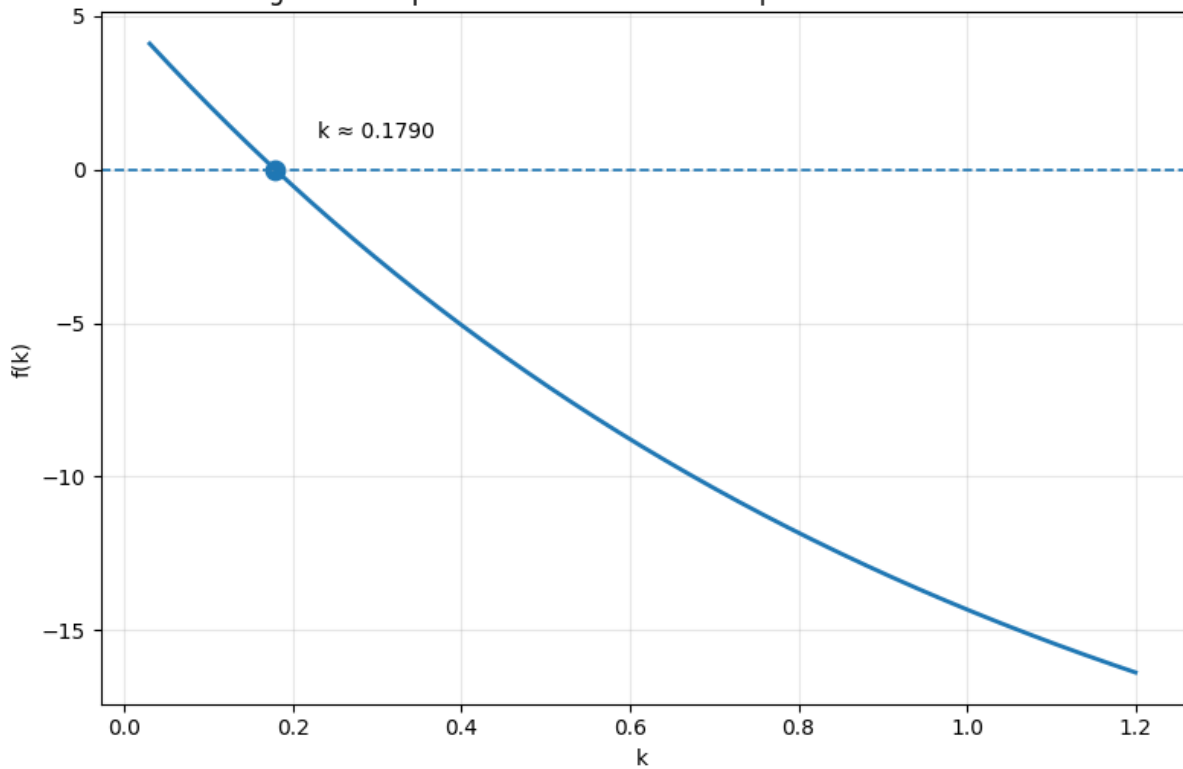
ax.text(t1_var + 1.15, T_found_1h_var + 2.0, "1
hour later \n25°C", fontsize=10)

ax.set_title("Figure 3. Temperature Dynamics Un-
der Variable Air Temperature")
ax.set_xlabel("Time (hours), relative to the time of
discovery ")
ax.set_ylabel("Temperature (°C)")
ax.grid(True, alpha=0.3)
ax.legend()

plt.tight_layout()
plt.savefig("fig3_variable_air_temp.png",
dpi=300, bbox_inches="tight")
plt.show()
plt.close()

```

Figure 4. Graph of the Transcendental Equation and Root Point



```

k_grid = np.linspace(0.03, 1.2, 800)
f_vals = [f_k_var(k) for k in k_grid]

fig, ax = plt.subplots(figsize=(8, 5.5))

ax.plot(k_grid, f_vals, linewidth=2)
ax.axhline(0, linestyle="--", linewidth=1.2)
ax.scatter([k_var], [0], s=80)

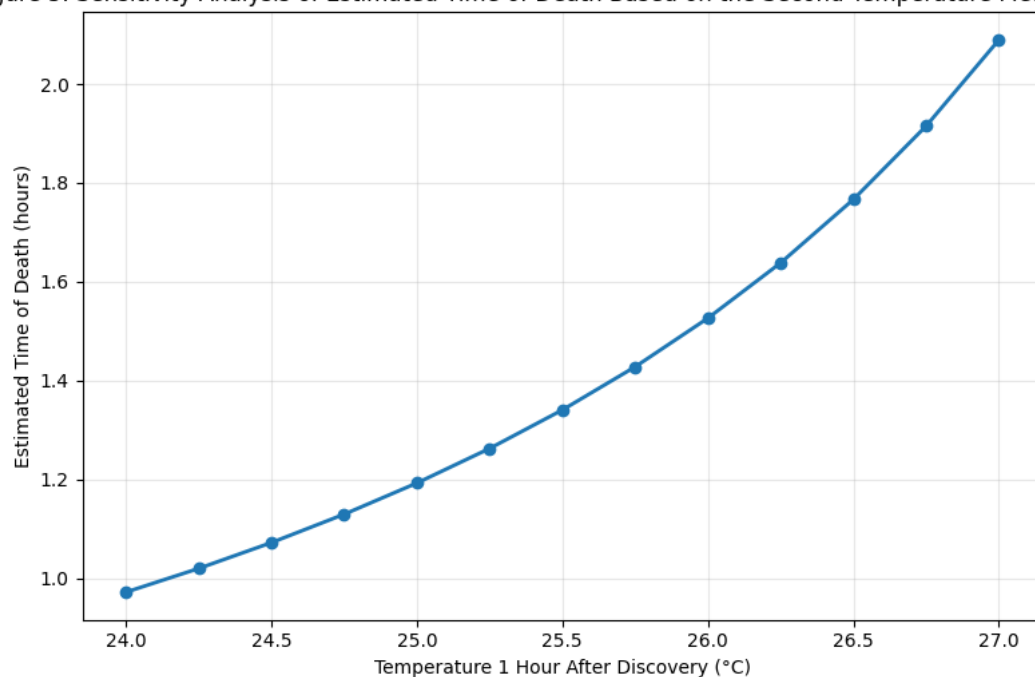
ax.text(k_var + 0.05, 1.0, f"k ≈ {k_var:.4f}", font-
size=10)

ax.set_title("Figure 4. Graph of the Transcenden-
tal Equation and Root Point")
ax.set_xlabel("k")
ax.set_ylabel("f(k)")
ax.grid(True, alpha=0.3)

plt.tight_layout()
plt.savefig("fig4_transcendental_root.png",
dpi=300, bbox_inches="tight")
plt.show()
plt.close()

```

Figure 5. Sensitivity Analysis of Estimated Time of Death Based on the Second Temperature Measurement



```
def solve_k_and_t1(T_found, T_found_1h):
```

```
def f(k):
```

```

    return (T_found - 1.0 / k) * math.exp(-k) -
(T_found_1h + 1.0) + 1.0 / k

    ak, bk = find_bracket(f, x_min=0.01, x_max=2.0)
    k_sol = bisection(f, ak, bk)

    def g(t1):
        return (37.0 - t1 - 1.0 / k_sol) * math.exp(-k_sol *
t1) + 1.0 / k_sol - T_found

    at, bt = find_bracket(g, x_min=0.01,
x_max=10.0)
    t1_sol = bisection(g, at, bt)
    return k_sol, t1_sol

T2_values = np.linspace(24.0, 27.0, 13)
estimated_times = []

for T2 in T2_values:
    _, t1_est = solve_k_and_t1(T_found_var, T2)
    estimated_times.append(t1_est)

fig, ax = plt.subplots(figsize=(8, 5.5))

ax.plot(T2_values, estimated_times, marker="o",
linewidth=2)

```

```

ax.set_title("Figure 5. Sensitivity Analysis of Es-
timated Time of Death Based on the Second Tempera-
ture Measurement")
ax.set_xlabel("Temperature 1 Hour After Discov-
ery (°C)")
ax.set_ylabel("Estimated Time of Death (hours)")
ax.grid(True, alpha=0.3)

plt.tight_layout()
plt.savefig("fig5_sensitivity_analysis.png",
dpi=300, bbox_inches="tight")
plt.show()
plt.close()

```

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SPATIAL MODES AND HELICAL STRUCTURE OF SWIRLING FLOW IN A CYLINDRICAL RESERVOIR WITH A STATIONARY CENTRAL ROD

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Abstract

This work investigates the spatial structure of swirling fluid flow in a cylindrical reservoir with a rotating disk and a stationary central rod. It is shown that an annular shear layer is formed near the rod surface and loses axial symmetry when the local Reynolds number exceeds a critical value. Spectral analysis demonstrates that the observed four-sector structure arises as a result of nonlinear interaction between the dipole mode $m = 2$ and its second harmonic $m = 4$. As the swirl intensity increases, the azimuthal modes acquire a longitudinal phase shift and form a spatial helical shell around the stationary rod. The mechanisms governing the stability of the structure, passive scalar transport, and the formation of secondary recirculation zones are analyzed. It is shown that the resulting structure does not represent an independent concentrated vortex core, but rather a spatially modulated surface of angular momentum transport and vorticity localization. A physical and mathematical model describing the spatial organization of helical modes in swirling flows is proposed.

Keywords: swirling flow; rotating disk; annular shear layer; helical mode; quadrupole instability; non-axisymmetric flow; coherent vortex structures; angular momentum transport; recirculation zones; helical vortex shell; vortex dynamics; cylindrical reservoir; stationary central rod; secondary toroidal vortices; modal instability.

1. Introduction. Swirling flows in confined cylindrical volumes are of considerable interest in fluid dynamics because such structures arise in vortex devices, rotary reactors, turbomachinery, vortex chambers, centrifugal separators, and intensive mixing systems. Particular attention is devoted to flows generated by rotating disks, in which radial momentum transport, axial circulation, and angular momentum redistribution occur simultaneously.

Classical studies of rotating flows demonstrate that, with increasing Reynolds number, an axisymmetric flow structure gradually loses stability and transitions to spatially nonuniform states [1-21]. The best-known examples include Taylor-Couette vortices, vortex breakdown, precessing vortex cores, and azimuthal modal structures.

Studies of swirling flows carried out by Alekseenko, Kuibin, and Okulov [13] are mainly devoted to concentrated vortex cores, helical vortex filaments, coherent structures, and spatial instabilities in swirling flows. These works provide a detailed analysis of the mechanisms responsible for the formation of spiral vortex structures, angular momentum redistribution, and the stability of vortex systems in confined volumes. Particular attention is paid to the spatial organization of vorticity and to the interaction between swirl and internal shear layers.

At the same time, the configuration considered in the present work differs substantially from classical models of concentrated helical vortices. The presence of a stationary central rod prevents the formation of a continuous vortex core in the axial region of the reservoir. As a result, the swirling flow reorganizes into an annular shear layer: $r_s < r < r_s + \delta_s$, where r_s is the radius of the stationary rod and δ_s is the characteristic thickness of the annular shear layer. Within this region,

an intense radial gradient of the azimuthal velocity, $\partial u_\varphi / \partial r \neq 0$, is formed and becomes the source of azimuthal instability. When the local Reynolds number $Re_s = U_\varphi \delta_s / \nu$, reaches critical values, where U_φ is the characteristic azimuthal velocity within the annular layer and ν is the kinematic viscosity of the fluid, a non-axisymmetric modal state develops, involving the dipole mode $m = 2$ and its nonlinear harmonic $m = 4$. This mode corresponds to the loss of complete axial symmetry and to the formation of four stable convective regions around the stationary rod. The perturbation field may be represented as

$$u'(r, \varphi, z) = A(r, z) \cos(4\varphi - kz) \quad (1)$$

where $A(r, z)$ describes the spatial distribution of the mode amplitude and k is the longitudinal wave-number of the helical structure. With further development of the swirl, the quadrupole mode acquires a spatial phase shift along the height of the reservoir, causing the transverse modal structures to merge into a unified three-dimensional helical shell surrounding the stationary rod. Unlike classical helical vortex filaments, the structure considered here does not represent an isolated concentrated vortex core but rather a spatially deformed annular layer of angular momentum transport.

An additional feature of the flow is the vertical transformation of the quadrupole mode. In the lower part of the reservoir, near the rotating disk, the shell possesses high energy and significant inertial stresses,

$$\sigma_i \sim \rho(u_s^2/R_c), \quad (2)$$

where u_s is the fluid velocity along the helical streamline and R_c is the local radius of curvature of the spatial shell. In this region, the maximum concentration of vorticity, strong nonlinear deformation of the mode, and intense pressure redistribution are observed.

As the distance from the rotating disk increases and the flow moves upward through the reservoir, the

amplitude of the spatial deformation decreases because of viscous dissipation and angular momentum redistribution. As a result, the helical shell gradually relaxes, becomes smoother, and approaches a quasi-stationary spatial state. Thus, the considered structure may be interpreted as a nonlinear coherent mode of an annular swirling layer in a confined cylindrical volume containing an internal stationary obstacle.

2. Geometry of the Problem. In the considered problem, a crucial role is played by the stationary central rod, which prevents the formation of a continuous vortex core in the axial region of the reservoir. As a consequence, the swirling flow reorganizes into an annular vortex structure surrounding the internal obstacle, within which an intense azimuthal velocity shear is formed.

The flow regime under consideration corresponds to tangential fluid injection through a side inlet, while a rotating disk transfers angular momentum to the flow. The central rod remains stationary, and the fluid is discharged through the lower part of the reservoir. Under these conditions, a stationary quadrupole azimuthal mode $m = 4$ develops within the annular shear layer, which subsequently transforms into a spatial helical shell as the swirl intensity increases. The investigated system consists of a cylindrical reservoir of radius R and height H . A rotating disk of radius b , rotating with a constant angular velocity Ω is located at the bottom of the reservoir. Along the axis of the reservoir, a stationary central rod of radius r_s is installed. Fluid is supplied tangentially through a side inlet and removed through a lower outlet channel.

The flow is described in cylindrical coordinates (r, φ, z) , where r is the radial coordinate, φ is the azimuthal angle, and, z is the vertical coordinate. The velocity field is represented as

$$\mathbf{u} = u_r \mathbf{e}_r + u_\varphi \mathbf{e}_\varphi + u_z \mathbf{e}_z. \quad (3)$$

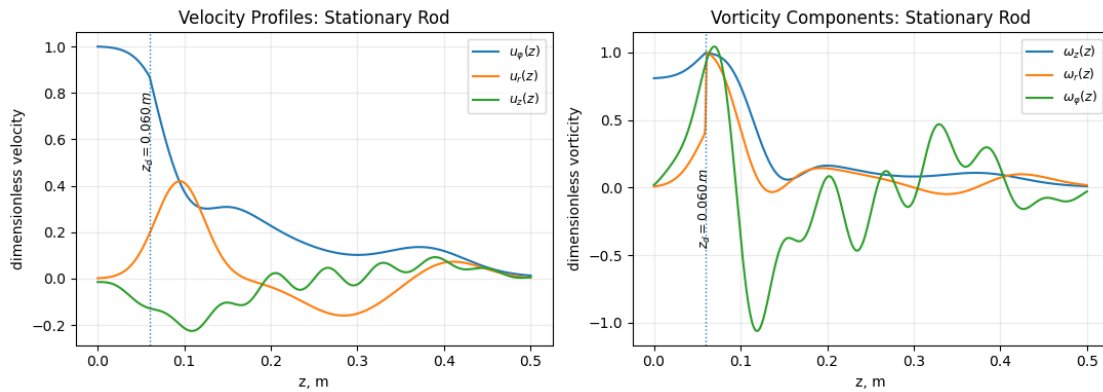


Figure 1. Dimensionless vertical profiles of velocity components and vorticity for a swirling flow in a cylindrical reservoir with a rotating disk and a stationary central rod. The plots demonstrate the influence of the internal obstacle on the redistribution of azimuthal velocity, the formation of the annular shear layer, and the emergence of localized regions of enhanced vorticity near the rod.

When the local Reynolds number reaches critical values $Re_s > Re_{cr}$, the axisymmetric flow loses stability and a non-axisymmetric azimuthal mode $m = 4$ appears within the annular layer. The perturbation field is represented as

$$u'(r, \varphi, z) = A(r, z) \cos(4\varphi - kz), \quad (7)$$

On the surface of the rotating disk, the rotational boundary condition is imposed: $u_\varphi(r, z = 0) = \Omega r$, where Ω is the angular velocity of the disk. On the surface of the stationary rod, the no-slip condition $u_\varphi(r_s) = 0$ is satisfied, leading to the formation of an intense radial gradient of the azimuthal velocity near the internal obstacle. The no-slip condition is also imposed at the outer wall of the reservoir $u_\varphi(R) = 0$.

Thus, the flow develops within a confined annular region between the stationary rod and the outer wall of the reservoir, where the interaction between rotational motion, viscosity, and geometric confinement gives rise to spatially nonuniform modal structures.

3. Governing Equations. The flow is described by the Navier–Stokes equations for an incompressible fluid:

$$\nabla \cdot \mathbf{u} = 0, \quad \rho((\partial \mathbf{u} / \partial t) + (\mathbf{u} \cdot \nabla) \mathbf{u}) = -\nabla p + \mu \nabla^2 \mathbf{u}, \quad (4)$$

where $\mathbf{u} = u_r \mathbf{e}_r + u_\varphi \mathbf{e}_\varphi + u_z \mathbf{e}_z$ is the velocity vector, p is the pressure, ρ is the fluid density, μ is the dynamic viscosity.

In cylindrical coordinates, the azimuthal momentum equation takes the form

$$\frac{\partial u_\varphi}{\partial t} + u_r \frac{\partial u_\varphi}{\partial r} + \frac{u_\varphi}{r} \frac{\partial u_\varphi}{\partial \varphi} + u_z \frac{\partial u_\varphi}{\partial z} + \frac{u_r u_\varphi}{r} = \nu \left(\nabla^2 u_\varphi - \frac{u_\varphi}{r^2} \right), \quad (5)$$

where ν is the kinematic viscosity of the fluid.

An intense annular shear layer is formed near the stationary central rod, within which a significant radial gradient of the azimuthal velocity $\partial u_\varphi / \partial r \neq 0$ develops. The principal dimensionless parameter of the flow is the Reynolds number,

$$Re_s = U_\varphi \delta_s / \nu, \quad (6)$$

where U_φ is the characteristic azimuthal velocity in the annular layer and δ_s is the characteristic thickness of the annular shear layer.

where $A(r, z)$ characterizes the spatial distribution of the mode amplitude and k is the longitudinal wave-number of the helical structure.

Due to the spatial phase shift, the transverse quadrupole modes merge into a unified helical shell representing a spatially deformed annular layer of angular momentum transport surrounding the stationary central rod. Type equation here.

3.1. Numerical Simulations. Numerical simulations were performed for an incompressible viscous fluid inside a cylindrical reservoir with a rotating disk and a stationary central rod. The computational domain was described in the cylindrical coordinate system (r, φ, z) , and the flow field was governed by the incompressible Navier–Stokes equations together with the continuity condition (4). A no-slip boundary condition was imposed at the surface of the rotating disk: $u_\varphi(r, z = 0) = \Omega r$, whereas at the surface of the stationary rod and at the cylindrical sidewall of the reservoir the condition $u_\varphi = 0$ was prescribed. The calculations were carried out for water with kinematic viscosity $\nu = 10^{-6} \text{ m}^2/\text{s}$. The geometric parameters of the system were chosen as follows: reservoir radius $R = 0.50 \text{ m}$, reservoir height $H = 0.50 \text{ m}$, rotating disk radius $b = 0.13 \text{ m}$, and central rod radius $r_s = 0.06 \text{ m}$. The angular velocity of the disk was set to $\Omega = 100 \text{ rad/s}$. To characterize the flow regime, the rotational Reynolds number was introduced: $Re_\Omega = \Omega R^2/\nu$. For the selected parameters, $Re_\Omega \approx 2.5 \times 10^7$, which corresponds to a strongly inertial flow regime in which viscous effects remain important only inside the boundary layers and within the annular shear layer formed near the stationary rod. The thickness of the viscous layer near the rotating disk was estimated using the von Kármán scaling: $\delta \sim \sqrt{\nu/\Omega} \approx 10^{-4} \text{ m}$. A boundary layer of the same order of magnitude is also formed near the surface of the stationary rod, where a strong radial gradient of azimuthal velocity develops: $\partial u_\varphi/\partial r \neq 0$. The numerical solution was constructed on the basis of an axisymmetric base flow followed by an analysis of spatial perturbations of the form given in equation (7). Vertical profiles of velocity and vorticity components were evaluated along the line $r = r_s + \delta_s$,

which passes through the region of maximum shear inside the annular layer.

Figure 1 illustrates the vertical distributions of the dimensionless velocity and vorticity components within the swirling flow near the stationary central rod. The left panel presents the profiles of the velocity components $u_\varphi(z)$, $u_r(z)$ and $u_z(z)$. The azimuthal velocity u_φ reaches its maximum near the rotating disk and gradually decreases with increasing axial coordinate z , reflecting the progressive dissipation and redistribution of angular momentum along the height of the reservoir. The radial velocity component u_r changes sign along the vertical direction, indicating the presence of toroidal recirculation. In the lower part of the reservoir the fluid is transported outward toward the periphery under the action of centrifugal forces, whereas in the upper region a compensating inward motion toward the axis is formed. The axial velocity u_z demonstrates the existence of a downward flow near the rod together with localized recirculation zones associated with the closure of the meridional circulation. The right panel shows the vorticity components $\omega_r(z)$, $\omega_\varphi(z)$ and $\omega_z(z)$. The maximum axial vorticity ω_z is localized near the surface of the stationary rod, where the annular shear layer with the strongest azimuthal velocity gradient is formed. The azimuthal vorticity ω_φ reflects the curvature of the meridional flow and is associated with the formation of secondary recirculation structures. The radial vorticity component ω_r exhibits an alternating-sign behavior caused by the spatial deformation of the annular vortex layer and the development of azimuthal instability modes. The oscillatory character of the vorticity profiles indicates the loss of complete axial symmetry and the onset of a spatially nonuniform helical structure developing around the stationary rod.

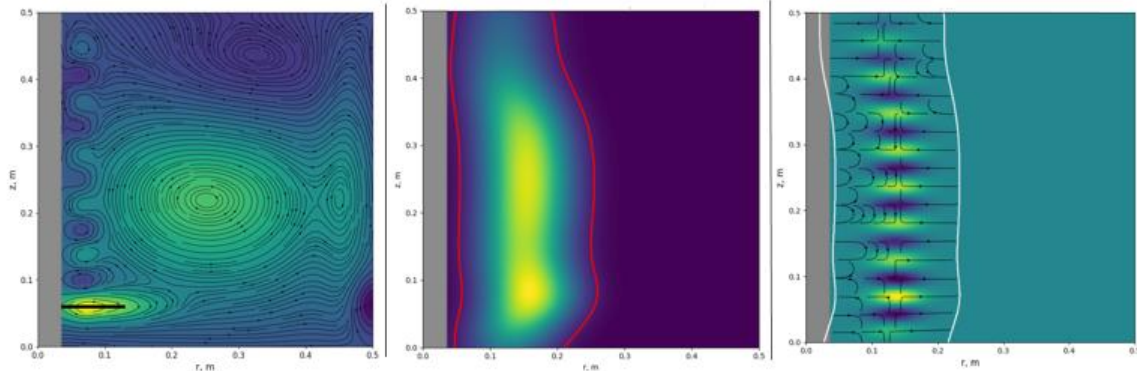


Figure 2. The longitudinal structure of a localized helical mode in a cylindrical reservoir with a stationary central rod. The left panel shows the streamline field and recirculation zones in the (r, z) plane, demonstrating the spatial reorganization of the swirling flow and the formation of localized vortex cells. The central panel presents the region influenced by the helical shell, determined by the distribution of the mode amplitude within the annular shear layer. The right panel shows the localized helical structure with suppression of the outer flow field, reflecting the spatial concentration of vorticity and recirculation zones near the stationary central rod.

4. Spectral Stability and Modal Structure of the Annular Shear Layer.

To determine the spatial structure of the most unstable perturbation, we consider the stability of the annular shear layer formed near the stationary central rod. In the axisymmetric base state, the azimuthal velocity depends only on the radial and axial coordinates r and z :

$$u_\varphi = u_{\varphi 0}(r, z). \quad (8)$$

The principal radial velocity gradient is localized inside the annular layer of thickness δ_s near the surface of the stationary rod ($\partial u_\varphi/\partial r \neq 0$). To analyze the stability of the flow, the velocity field is represented as the sum of the base flow and a small perturbation:

$$\mathbf{u} = \mathbf{u}_0 + \mathbf{u}', \quad (9)$$

where $\mathbf{u}_0$ corresponds to the mean swirling flow, while $\mathbf{u}'$ describes the spatial modal structure of the perturbation. For the analysis of the spatial instability structure, the perturbation field is expanded into azimuthal Fourier modes:

$$u'(r, \varphi, z, t) = \sum_{m=0}^{\infty} A_m(r, z, t) \exp(im\varphi), \quad (10)$$

where m denotes the azimuthal wave number, while $A_m(r, z, t)$ characterizes the spatial amplitude of the corresponding mode. Such a decomposition makes it possible to represent an arbitrary non-axisymmetric perturbation as a superposition of azimuthal harmonics of different orders.

Each individual harmonic may be represented in the form of a wave-like perturbation:

$$A_m(r, z, t) = \hat{u}_m(r, z) \exp(-i\omega t), \quad (11)$$

where $\omega = \omega_r + i\omega_i$ is the complex frequency. The perturbation field corresponding to an individual mode therefore takes the form $\omega_i > 0$ corresponds to exponential growth of the modal amplitude and indicates hydrodynamic instability of the annular shear layer.

Each value of m corresponds to a specific spatial symmetry of the flow. The mode $m = 0$ describes an axisymmetric state, $m = 1$ corresponds to a one-sided displacement of the vortex structure, and $m = 2$ forms a dipole configuration, whereas $m = 4$ corresponds to a quadrupole structure with four azimuthal regions of enhanced vorticity (Table1)..

Table 1.

Relationship Between Azimuthal Modes and Swirl Intensity

Regime	Most Probable Mode
Weak swirl	$m = 0$
Moderate swirl	$m = 1$
Strong annular shear	$m = 2$
Thin strongly sheared layer	$m = 3 - 4$

Spectral analysis of the velocity and vorticity fields demonstrates that, upon reaching a critical value of the local Reynolds number, the spectrum exhibits pronounced contributions of both the dipole mode $m = 2$ and the quadrupole harmonic $m = 4$. This indicates that the quadrupole perturbation acquires the largest growth rate and becomes the dominant spatial structure of the annular shear layer. As a result, the flow loses complete axial symmetry and reorganizes into a four-lobed helical shell surrounding the stationary central rod.

The presence of a longitudinal phase shift produces an additional spatial modulation:

$$u'(r, \varphi, z) = A(r, z) \cos(4\varphi - kz), \quad (12)$$

where k denotes the axial wave number of the helical structure. This expression describes the spatial rotation of the quadrupole mode along the height of the reservoir and the formation of a helical shell inside the annular shear layer.

Linearization of the Navier–Stokes equations about the base state leads to a spectral stability problem for the annular shear layer. The principal instability mechanism is associated with a combination of centrifugal instability and Kelvin–Helmholtz-type shear instability. For $\Omega = u_\varphi/r$ the necessary condition for instability is determined by the Rayleigh–Fjørtoft criterion:

$$\frac{\partial}{\partial r} \left[\frac{1}{r^3} \frac{\partial(r^2 \Omega)}{\partial r} \right] = 0. \quad (13)$$

Since the azimuthal velocity profile near the stationary rod possesses a pronounced inflection point, the

instability criterion is satisfied inside the annular shear layer. The characteristic azimuthal wave number of the fastest-growing mode is determined by the ratio between the radius of the annular layer and its thickness. For an annular structure with radius r_s and thickness δ_s , the characteristic azimuthal wavelength may be estimated as $\lambda_\varphi \sim 2\pi\delta_s$. The corresponding number of azimuthal modes distributed along the circumference is therefore given by

$$m_* \sim 2\pi r_s / \lambda_\varphi \sim r_s / \delta_s. \quad (14)$$

For the flow parameters considered in the present study, the ratio r_s/δ_s is of the order of several units, as a result of which the quadrupole harmonic $m = 4$ becomes clearly observable in the developed nonlinear regime. This mode corresponds to the formation of four azimuthal regions of enhanced vorticity and localized pressure reduction around the stationary rod. The spatial structure of the perturbation is described by equation (7).

Modes with smaller values of m possess insufficient spatial localization and therefore do not provide stable separation of the annular layer, whereas modes with larger m are strongly suppressed by viscous dissipation due to their small azimuthal scales. Consequently, the quadrupole mode represents a compromise between inertial amplification and viscous damping and therefore acquires the maximum growth rate.

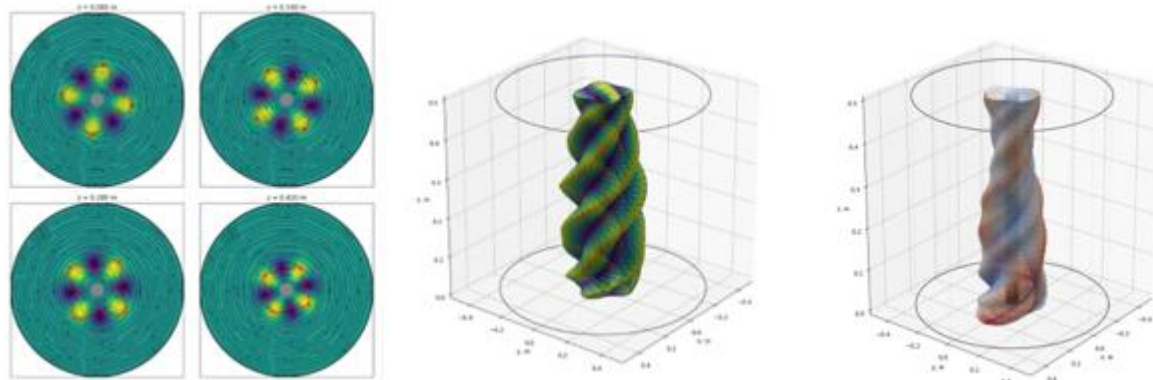


Figure 3. Transverse cross-sections of the quadrupole azimuthal mode and the corresponding spatial helical shell in a cylindrical reservoir with a rotating disk and a stationary central rod. The left panel shows the transverse structures of the mode $m = 4$, forming four stable convective regions around the rod. The rotation of the structure along the reservoir height reflects the presence of a phase shift $\theta(z) = kz$. The central panel presents the three-dimensional helical shell arising from the spatial connection of the transverse modal structures within the annular shear layer. The right panel shows a mixed helical shell $m = 2 + m = 4$ with a semi-conical expansion in the vicinity of the rotating disk.

As a result, the annular shear layer loses its complete axial symmetry and reorganizes into a spatial quadrupole helical shell surrounding the stationary central rod.

The emergence of this mode leads to the loss of complete axial symmetry of the flow and to the division of the annular vortex layer into four spatially organized regions. In the transverse cross-section of the reservoir, sectors of intensified swirl, locally reduced pressure, enhanced vorticity, and radial momentum transport are formed.

The pressure field may be represented as

$$p(r, \varphi, z) = p_0(r, z) + P_4(r, z) \cos(4\varphi), \quad (15)$$

where $p_0(r, z)$ corresponds to the axisymmetric pressure component and $P_4(r, z)$ describes the amplitude of the quadrupole modulation.

The azimuthal pressure nonuniformity leads to the formation of four stable convective regions around the stationary rod. Within these regions, local recirculation flows and zones of enhanced vorticity develop due to the redistribution of angular momentum inside the annular shear layer. With further development of the swirl, the transverse quadrupole structures acquire a spatial phase shift along the height of the reservoir and transform into a three-dimensional helical shell.

Table 2.

Comparison of Azimuthal Modes of the Annular Shear Layer

Mode m	Spatial Structure	Number of Azimuthal Regions	Stability Characteristics	Physical Interpretation
$m = 0$	Axisymmetric flow	0	Stable at low Re	Uniform annular rotation without spatial deformation
$m = 1$	Single-lobe asymmetry	1	Weakly stable	Displacement of the vortex core relative to the reservoir axis
$m = 2$	Dipole structure	2	Moderately stable	Formation of two opposite regions of intensified swirl
$m = 3$	Three-lobed mode	3	Limited stability	Spatially nonuniform vorticity distribution with increased dissipation
$m = 4$	Quadrupole helical mode	4	Most stable	Formation of four stable channels of angular momentum transport around the rod

As follows from Table 2, the mode $m = 4$ represents an optimal compromise between inertial amplification and viscous dissipation. Modes with smaller values of m possess insufficient spatial localization and do not provide stable separation of the annular shear layer, whereas modes with larger values of m are suppressed by viscous dissipation due to the decreasing azimuthal scale of the perturbations. As a result, for the flow pa-

rameters considered in the present study, the quadrupole mode exhibits the largest growth rate and forms a spatial helical shell around the stationary central rod.

4.1 Spectral Structure of Azimuthal Perturbations.

For a more accurate description of the spatial flow structure, it is necessary to take into account that the observed four-lobed pattern may not represent an independent primary $m = 4$ mode, but rather the result of a nonlinear superposition of the fundamental dipole

mode $m = 2$ and its second harmonic $m = 4$. In this case, the perturbation field may be written as

$$u'(r, \varphi, z, t) = A_2(r, z, t) \cos(2\varphi - k_2 z - \omega_2 t) + A_4(r, z, t) \cos(4\varphi - k_4 z - \omega_4 t), \quad (16)$$

where the first term describes the large-scale dipolar deformation of the annular shear layer, while the second term represents the quadrupole modulation responsible for the formation of four localized regions of enhanced vorticity around the stationary rod. Such a solution corresponds to a mixed modal state in which the global instability is primarily associated with the $m = 2$ mode, whereas the observed four-sector structure is amplified by the harmonic $m = 4$.

The emergence of the harmonic $m = 4$ naturally follows from the nonlinear terms of the Navier–Stokes equations. If a dipole perturbation is already present in the flow,

$$u'_2 = A_2 \cos(2\varphi - k_2 z), \quad (17)$$

then the quadratic inertial term $(\mathbf{u}' \cdot \nabla) \mathbf{u}'$ contains the self-product of this mode:

$$\cos^2(2\varphi - k_2 z) = 0.5 [1 + \cos(4\varphi - 2k_2 z)]. \quad (18)$$

Thus, quadratic nonlinear interactions naturally transfer energy from the dipole mode to its second azimuthal harmonic. It follows from this expression that self-interaction of the $m = 2$ mode automatically generates the second harmonic $m = 4$. Therefore, the presence of a quadrupole structure does not necessarily imply that $m = 4$ represents an independent primary instability. Instead, it may arise as a nonlinear harmonic of the dipole instability. In this case, the spectral representation of the perturbation takes the form given by equation (10), while in the developed regime the dominant part of the perturbation energy is concentrated in two azimuthal modes:

$$|A_2| > 0, |A_4| > 0, \quad (19)$$

whereas the remaining harmonics possess substantially smaller amplitudes:

$$|A_m| \ll |A_2| + |A_4|, m \neq 2, 4 \quad (20)$$

The criterion of the mixed regime is the presence of two pronounced peaks in the azimuthal spectrum of vorticity or velocity:

$$E_m(z) = \left| \int_0^{2\pi} \omega_z(r, \varphi, z) \exp(-im\varphi) d\varphi \right|^2, \quad (21)$$

where E_m denotes the azimuthal spectral energy density of the mode m .

If the spectrum exhibits a maximum at $m = 2$ together with a pronounced second harmonic at $m = 4$, then the observed structure should be interpreted as a superposition $m = 2 + m = 4$. In this case, the four-lobed pattern represents the result of nonlinear amplification of the second harmonic rather than evidence of the primary selection of a purely quadrupole mode.

Thus, the most physically consistent interpretation is that the stationary central rod forms an annular shear layer that initially loses stability through the dipole mode $m = 2$. As the swirl intensity increases, nonlinear self-interaction of this mode generates the harmonic $m = 4$, resulting in the formation of a four-sector spatial structure around the rod. In the presence of a longitudinal phase shift, both modes acquire a helical character, and the perturbation field may be described as a mixed helical shell:

$$u'(r, \varphi, z) = A_2(r, z) \cos(2\varphi - k_2 z) + A_4(r, z) \cos(4\varphi - k_4 z) \quad (22)$$

During the development of the dipole mode $m = 2$, the annular shear layer ceases to be azimuthally uniform. In two opposite sectors, a local amplification of the azimuthal velocity gradient and a concentration of vorticity arise. As a consequence of nonlinear advection, these regions undergo additional deformation and localized azimuthal compression. This process leads to a local densification of streamlines and a concentration of angular momentum within individual regions of the annular shear layer.

Since the convective transport term in the Navier–Stokes equations is quadratic, amplification of the dipole structure automatically generates a second azimuthal harmonic. Physically, this corresponds to the splitting of two large-scale vortex regions into four localized sectors of enhanced vorticity. As a result, the initial dipole mode gradually acquires a pronounced quadrupole modulation.

Thus, the $m = 4$ structure does not arise as an independent primary instability, but rather as a consequence of nonlinear redistribution of vorticity and spatial concentration of energy within the dipolar annular shear layer.

5. Formation of the Thin Annular Shear Layer.

The rotating disk transfers angular momentum to the fluid, resulting in the formation of an intense swirling motion within the reservoir: $u_\varphi \sim \Omega r$. However, the presence of the stationary central rod suppresses the rotation of the fluid in the axial region. As a consequence, a continuous axial vortex core cannot form, and the flow reorganizes into an annular vortex layer: $r_s < r < r_s + \delta_s$. Within this region, an intense radial gradient of the azimuthal velocity $\partial u_\varphi / \partial r \neq 0$, is generated, becoming the source of azimuthal hydrodynamic instability. The maximum values of the velocity gradient are localized near the surface of the stationary rod, where the azimuthal motion is strongly decelerated due to the no-slip boundary condition $u_\varphi(r_s) = 0$.

Physically, the stationary rod acts as an internal obstacle suppressing the formation of a continuous axial vortex core. As a result, the swirling flow acquires the structure of a hollow vortex shell, within which the primary transport of angular momentum occurs in the annular region between the rod surface and the outer part of the reservoir.

6. Formation of the Helical Shell

Inside the annular shear layer, intense swirl, radial momentum transport, and local concentration of vorticity coexist simultaneously. The axial vorticity is defined as

$$\omega_z = (1/r) (\partial(r u_\varphi) / \partial r). \quad (23)$$

As the swirl intensity increases, the layer loses complete axial symmetry, leading to the emergence of non-axisymmetric azimuthal modes. Within the considered parameter range, the observed quadrupole structure is interpreted as a mixed modal state involving the dipole mode $m = 2$ and its nonlinear harmonic $m = 4$, leading to the formation of four convective regions around the stationary rod. With further development of the swirl, these transverse structures acquire a spatial phase shift along the height of the reservoir and merge

into a coherent helical shell of the deformed annular vortex layer.

The appearance of longitudinal phase modulation means that the maxima of the quadrupole mode become displaced in the azimuthal direction as the coordinate z changes. As a result, the transverse convective regions lose their independence and merge into a unified spatial structure. Individual regions of enhanced vorticity become connected along helical trajectories, forming spatial channels of angular momentum transport. The trajectory of the maxima of the helical shell is determined by

$$\varphi(z) = \varphi_0 + kz + \varphi_m, \quad (24)$$

where φ_0 corresponds to the initial azimuthal position of the mode.

Thus, the transverse quadrupole structure transforms into a spatial helical shell of the deformed annular vortex layer. Unlike classical concentrated helical vortices, the considered shell represents a spatially modulated surface of angular momentum transport localized within the annular shear layer surrounding the stationary central rod.

Inside the helical shell, maximum values of local vorticity, intense radial-azimuthal momentum transport, and reduced pressure are observed. At the same time, the shell preserves its coherence due to the balance between centrifugal forces, pressure gradients, and viscous dissipation. The spatial deformation of the structure is accompanied by the formation of local recirculation regions and secondary toroidal vortex zones interacting with the primary helical flow.

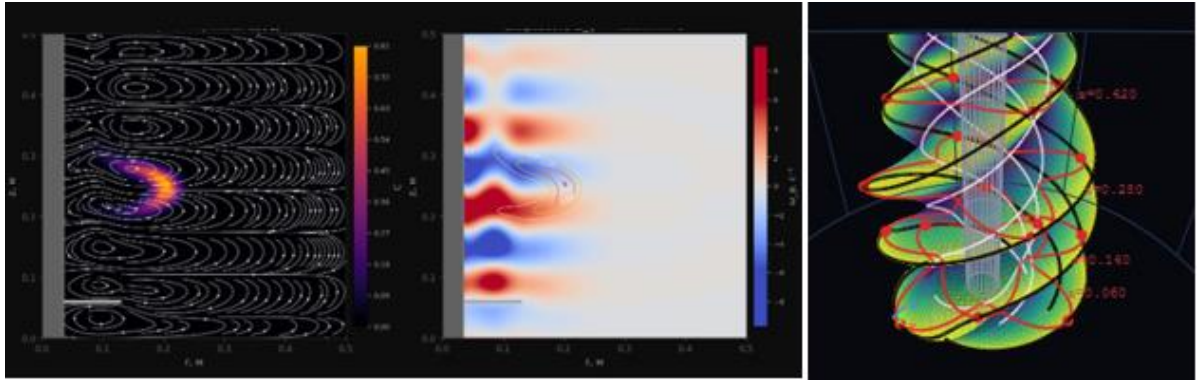


Figure 4. The spatial organization of a quadrupole helical mode in a swirling fluid flow within a cylindrical reservoir with a rotating disk and a stationary central rod. The left panel shows the impurity concentration distribution in a longitudinal cross-section, demonstrating the localization of mass transport inside the helical shell and the formation of closed recirculation zones. The central panel presents the vorticity field and streamlines, illustrating the spatial deformation of the annular shear layer and the emergence of the nonlinear azimuthal mode (1). The right panel depicts the three-dimensional helical shell of the quadrupole mode formed around the stationary rod as a result of the phase shift of transverse structures along the height of the reservoir. The surface color modulation reflects the spatial distribution of swirl intensity and local vorticity within the deformed annular layer of angular momentum transport.

Unlike classical helical vortex filaments, the considered structure does not form a continuous rotating vortex core. The primary transport of angular momentum occurs within the deformed annular shear layer, which spatially envelops the stationary rod and forms a coherent helical shell.

As the distance from the rotating disk increases, the deformation amplitude $A(z)$ decreases due to viscous damping and energy redistribution within the main fluid volume. As a consequence, the helical shell gradually becomes smoother and transitions toward a more axisymmetric spatial state.

7. Internal Force Balance. The stability of the helical shell is determined by the interaction of several hydrodynamic mechanisms. The principal role is played by the balance between centrifugal forces, pressure gradients, viscous dissipation, and the spatial curvature of streamlines inside the annular vortex layer.

Due to the intense azimuthal motion within the shell, centrifugal forces arise that tend to expand the vortex structure in the radial direction:

$$F_c = \rho(u_\varphi^2/r). \quad (25)$$

This radial expansion is counteracted by the radial pressure gradient,

$$\partial p / \partial r = \rho(u_\varphi^2/r), \quad (26)$$

as a result of which a self-consistent pressure field is formed inside the shell. Thus, the spatial structure is maintained not by geometric confinement alone but by the internal balance between centrifugal expansion and pressure gradients. This gives the helical shell the properties of an internally organized coherent hydrodynamic structure. An additional role is played by viscous interaction. On the surface of the stationary rod, the no-slip condition: $u_\varphi(r_s) = 0$ is satisfied, whereas inside the annular layer the azimuthal velocity remains substantial. Consequently, an intense shear stress arises:

$$\tau_{r\varphi} = \mu(\partial u_\varphi / \partial r) \quad (27)$$

which tends to smooth azimuthal nonuniformities and restore the axisymmetric flow state. Viscosity therefore acts as a dissipation mechanism reducing the amplitude of the spatial mode. At the same time, the rotating disk continuously supplies angular momentum to the system:

$$M \sim \rho \Omega^2 b^5 \quad (28)$$

where Ω is the angular velocity of the disk and b is its radius. As a result, a dynamic balance is established inside the reservoir between energy input and

viscous dissipation. As long as this balance is maintained, the helical shell remains stable.

A significant influence is also exerted by the spatial curvature of the helical structure. Since the streamlines are curved along helical trajectories, additional inertial stresses arise inside the shell:

$$\sigma_i \sim \rho(u_s^2/R_c), \quad (29)$$

where u_s is the velocity along the helical streamline and R_c is the local radius of curvature of the shell. These inertial stresses tend to straighten the helical structure and reduce its spatial curvature. However, the spatial azimuthal mode simultaneously generates alternating regions of reduced and elevated pressure, producing a self-consistent force distribution that maintains the shell geometry. An important role is also played by the vorticity balance, $\boldsymbol{\omega} = \nabla \times \mathbf{u}$. Inside the annular layer, a local concentration of vorticity is observed, although its accumulation is limited by spatial redistribution processes. Part of the vorticity is transported upward along the helical channels, part is dissipated by viscosity, and part becomes involved in secondary toroidal recirculation structures. As a consequence, the helical shell continuously exchanges momentum and vorticity with the surrounding fluid volume while preserving its coherent spatial organization.

8. Secondary Toroidal Structures. The spatial helical shell causes pressure redistribution throughout the reservoir volume, resulting in the formation of secondary toroidal recirculation zones within the flow. In this case, the pressure field may be represented as

$$p = p_0 + P_4 \cos(4\varphi - kz) + P_t(r, z) \quad (30)$$

where p_0 corresponds to the axisymmetric pressure component, P_4 characterizes the azimuthal modulation associated with the quadrupole mode, and, $P_t(r, z)$ describes the additional pressure induced by the secondary toroidal flows.

Toroidal structures are formed in regions where a longitudinal pressure gradient, $\partial p / \partial z \neq 0$ appears. In these zones, closed circulation contours arise: $\oint \mathbf{u} \cdot d\mathbf{l} \neq 0$, corresponding to localized fluid recirculation regions.

The formation of toroidal structures is associated with the spatial nonuniformity of the helical shell and with the redistribution of angular momentum along the reservoir height. In regions of reduced pressure, the flow is drawn into the helical channels, whereas in regions of elevated pressure a reverse fluid motion develops.

As a consequence, a system of closed toroidal circulations interacting with the primary swirling flow is formed inside the reservoir. The toroidal recirculation zones modify the local distributions of velocity, pressure, and vorticity, and also influence impurity transport and the spatial stability of the helical shell. Within these regions, additional local potential zones arise in which the fluid may perform long-term circulatory motion around the helical structure.

9. Impurity Transport. The motion of a dye droplet inside the swirling flow in a cylindrical reservoir with a rotating disk and a stationary central rod is considered. After being introduced into the flow, the droplet is initially entrained into the primary rotational

motion of the fluid and begins to move around the rod under the action of the azimuthal velocity component. Its trajectory is determined by the superposition of the azimuthal, radial, and axial velocity components defined in Eq. (3).

At the initial stage of motion, the droplet rapidly acquires azimuthal velocity:

$$d\varphi/dt = u_\varphi/r \approx \Omega \quad (31)$$

and begins to rotate around the central rod. Simultaneously, centrifugal forces generate radial fluid transport:

$$dr/dt = u_r, F_c = \rho(u_\varphi^2/r), \quad (32)$$

as a result of which the droplet trajectory ceases to be circular and acquires a spiral form. In the lower part of the reservoir, where the influence of the rotating disk is maximal, the droplet moves along an expanding helical trajectory:

$$dr/dt > 0, d\varphi/dt = u_\varphi/r \quad (33)$$

As the droplet approaches the stationary rod, the flow decelerates due to the no-slip condition $u_\varphi(r_s) = 0$. Consequently, an annular shear layer is formed around the rod:

$$\partial u_\varphi / \partial r \neq 0, \quad (34)$$

within which the droplet undergoes intense stretching and deformation along the streamlines. Entering the region of the helical shell, the droplet begins to follow the spatial geometry of the modal structure. Its trajectory acquires the form of a helical line:

$$\varphi(z) = \varphi_0 + kz, \quad (35)$$

where k is the longitudinal wavenumber of the helical mode.

If the flow remains stable, the droplet motion becomes localized inside one of the four azimuthal channels of the quadrupole mode described by

$$u'(r, \varphi, z) = A(r, z) \cos(4\varphi - kz). \quad (36)$$

In regions of reduced pressure,

$$p(r, \varphi, z) = p_0(r, z) + P_4(r, z) \cos(4\varphi - kz) \quad (37)$$

the droplet accelerates and is drawn into the helical shell, whereas in regions of elevated pressure its motion slows down. As a result, the trajectory becomes spatially nonuniform: along the helical structure the droplet periodically accelerates and decelerates.

As the droplet propagates upward through the reservoir, it becomes involved in the spatial circulation of the flow. Part of the impurity is transported upward along the helical channels and may subsequently become entrained into secondary toroidal recirculation zones. Within such regions, closed circulation contours arise:

$$\oint \mathbf{u} \cdot d\mathbf{l} \neq 0, \quad (38)$$

corresponding to repeated circulatory fluid motion around the helical shell.

If the droplet enters the interaction region between the helical shell and a secondary toroidal vortex, the trajectory acquires a complex spatial structure. The motion then consists of two superposed rotations: a rapid azimuthal motion around the rod and a slower toroidal transport along closed recirculation contours. As a consequence, the trajectory assumes the form of a spatial epicycloidal spiral.

Over time, the droplet is stretched due to shear stresses:

$$\tau = \mu(\partial u_\varphi / \partial r), \quad (39)$$

causing the initially compact impurity region to transform into a thin helical filament re-producing the geometry of the vortex shell. The further evolution of the impurity is governed by the combined action of advection and diffusion and is described by the transport equation

$$(\partial C / \partial t) + (u \cdot \nabla)C = D \nabla^2 C, \quad (40)$$

where $C(r, \varphi, z, t)$ is the dye concentration and D is the coefficient of molecular diffusion.

At the initial stage, advective transport dominates:

$$(u \cdot \nabla)C \gg D \nabla^2 C, \quad (41)$$

therefore the impurity is stretched into a long helical structure whose shape is determined by the geometry of the vortex shell and the secondary recirculation zones. At later stages, diffusive smoothing becomes increasingly important, causing the concentration to gradually equalize throughout the reservoir volume

Thus, impurity transport in the considered flow is governed by the spatial organization of the swirling motion. The droplet is successively entrained into the primary rotation, drawn into the helical shell surrounding the stationary rod, interacts with secondary toroidal structures, and gradually transforms into a complex three-dimensional helical concentration structure.

10. r-z Cross-Section: Longitudinal Structure (Fig. 2a and 4a). In the axisymmetric base state, $\partial/\partial\varphi = 0$ and Eq. (5) reduces to the diffusion-convection transport equation for the angular velocity $\Omega(r, z) = u_\varphi/r$:

$$\frac{\partial \Omega}{\partial t} + u_r \frac{\partial \Omega}{\partial r} + u_z \frac{\partial \Omega}{\partial z} = \nu \left[\frac{\partial^2 \Omega}{\partial r^2} + \frac{3}{r} \frac{\partial \Omega}{\partial r} + \frac{\partial^2 \Omega}{\partial z^2} \right] \quad (42)$$

The operator containing the coefficient $3/r$ in front of the first radial derivative reflects not the diffusion of a scalar quantity but the diffusion of angular momentum $L = r^2 \Omega$, for which the equation may be re-written as

$$\frac{\partial L}{\partial t} + u_r \frac{\partial L}{\partial r} + u_z \frac{\partial L}{\partial z} = \nu \left[\frac{\partial^2 L}{\partial r^2} + \frac{3}{r} \frac{\partial L}{\partial r} + \frac{\partial^2 L}{\partial z^2} \right] \quad (43)$$

This clearly demonstrates that angular momentum L transport is suppressed by the centrifugal term, causing angular momentum to concentrate near the outer wall, while a sharp radial velocity gradient forms near the rod. The meridional flow (u_r, u_z) is determined from the continuity condition

$$(\partial(r u_r) / \partial r) + r(\partial u_z / \partial z) = 0 \quad (44)$$

together with the momentum equations for the radial and axial velocity components.

Near the rotating disk, a von Kármán layer develops: the fluid is spun up by the disk, centrifugal forces eject it radially outward, and the axial pressure gradient generates a compensating downward axial inflow. Along the axis (or near the rod), a descending flow is formed with a characteristic velocity of the order $u_z \sim -\nu^{1/2} \Omega_d^{1/2}$, which reaches its maximum inside the von Kármán layer and decreases according to a power law with increasing distance from the disk. Outside the annular shear layer, a weak upward recirculation develops, closing the meridional circulation cell. Consequently, the dependence $u_z(r)$ becomes sign-changing: near r_s a negative minimum is observed, whereas for $r > r_s$ the velocity becomes weakly positive.

Radial momentum transport also exhibits a dual structure. Near the upper boundary, tangential injection produces a weak inward-directed flow: the fluid acquires swirl and slowly drifts toward the axis. Near the bottom, in contrast, a weak outward radial flow develops. Therefore, impurity particles introduced from above experience both axial descent and a slow inward radial drift, making their trajectories fundamentally different from purely vertical settling.

The azimuthal velocity field inside the annular layer is well approximated by

$$u_\varphi(r, z) = U_0 f(z) g(r), \quad (45)$$

where $f(z) = (z/H)^\alpha$, $g(r) = \tanh((r - r_s)/\delta_s)$. The function $f(z)$ describes the weakening of the disk influence with height ($\alpha \approx 0.5 - 1$), a $g(r)$ models a shear layer of thickness δ_s . The radial shear reaches its maximum at $r = r_s$:

$$\left. \frac{\partial u_\varphi}{\partial r} \right|_{r=r_s} = \frac{U_0 f(z)}{\delta_s}. \quad (46)$$

The key stability parameter is the Reynolds number of the layer $Re_s = U_0 \delta_s / \nu$. When the critical value $Re_s^* \approx 150 - 300$ is exceeded, the axisymmetric flow becomes unstable with respect to azimuthal perturbations.

The stability of the annular layer is governed by the competition between centrifugal forces and Kelvin-Helmholtz-type shear instability. A necessary instability condition is given by the generalized Rayleigh-Fjørtoft criterion:

$$\frac{\partial}{\partial r} \left[\frac{1}{r^3} \frac{\partial(r^2 \Omega)}{\partial r} \right] = 0. \quad (47)$$

This condition implies the presence of an inflection point in the circulation distribution. In the considered annular layer, such an inflection point exists by construction and is localized near r_s ; therefore, azimuthal modes $m = 1, 2, 3$ arise at sufficiently large Reynolds numbers. For typical parameters, the dominant nonlinear modal state involves the dipole mode $m=2$ together with its second harmonic $m = 4$.

The growth of this mode is described as a small perturbation of the base flow:

$$u_\varphi(r, \varphi, z, t) = U_0(r, z) + \varepsilon \hat{u}_\varphi(r, z) \cos(m\varphi - \omega t), \quad (48)$$

where the complex frequency $\omega = \omega_r + i\omega_i$ has a positive imaginary part $\omega_i > 0$ in the unstable region. The eigenfunction $\hat{u}_\varphi(r, z)$ is localized near r_s and decays exponentially on both sides of the layer. Along the axis, it forms a standing or weakly traveling wave with axial wavenumber k_z , while the phase velocity $c_{ph} = \omega_r/m$ is close to the mean azimuthal velocity inside the layer. It is precisely this spatially periodic structure that forms the observed “shell.” The constant-amplitude surface of the perturbation is described as a deformed cylinder:

$$r_{shell}(\varphi, z) = r_s + A \cos[m(\varphi - k_z z)], \quad (49)$$

where $k_z = \pi/Hn$ for an integer number of half-waves n along the reservoir height. In the $r - z$ cross-section, after averaging over φ , only the envelope of this structure is observed - two nearly vertical bands located on both sides of r_s within which vorticity is concentrated.

For an axisymmetric flow, the vertical vorticity component is

$$\omega_z = (1/r)(\partial(ru_\phi)/\partial r), \quad (50)$$

while the azimuthal component is

$$\omega_\phi = (\partial u_r/\partial z) - (\partial u_z/\partial r). \quad (51)$$

For the profile

$$g(r) = \tanh((r - r_s)/\delta_s) \quad (52)$$

one obtains

$$\omega_z(r) \approx (U_0 f(z)/\delta_s) \operatorname{sech}^2((r - r_s)/\delta_s), \quad (53)$$

that is, a function possessing a sharp maximum at r_s and a characteristic width of order δ_s .

The total circulation flux through a horizontal cross-section,

$$\Gamma = \oint u_\phi dl = 2\pi r u_\phi \quad (54)$$

decreases with increasing distance from the disk due to viscous dissipation and axial transport:

$$\frac{\partial \Gamma}{\partial z} = \nu r \frac{\partial}{\partial r} \left[\frac{1}{r} \frac{\partial(ru_\phi)}{\partial r} \right] \frac{r}{u_z} \quad (55)$$

This corresponds to the gradual spreading of the annular vortex layer as the fluid is transported upward.

The velocity vectors in the r - z cross-section reflect the meridional circulation: inside the annular layer ($r \approx r_s$), the vector (u_r, u_z) is directed downward and slightly inward, forming a descending spiral. Outside the layer ($r > r_s$), a weak upward motion develops, closing the toroidal circulation cell. Near the rod, the pressure is reduced because of the centrifugal deficit; therefore, a weak descending flow usually persists directly along the rod surface.

The combination of these processes forms the observed pattern: a vertically elongated closed vortex layer with radius r_s , a descending core, and an ascending periphery. It is precisely along this descending spiral trajectory that a passive impurity introduced from above is transported toward the disk while simultaneously spreading azimuthally due to molecular and turbulent diffusion.

11. Diffusion and circulation (numerical calculation).

The constructed model considers an axisymmetric viscous flow of an incompressible fluid in a cylindrical reservoir with a stationary sidewall and central rod, a rotating disk at the bottom end, and tangential fluid injection at the upper boundary. The main tool for describing the meridional flow is the stream function $\psi(r, z)$, introduced from the incompressibility condition $\nabla \cdot \mathbf{u} = 0$. In cylindrical coordinates, the continuity equation is written as follows:

$$(1/r)(\partial(ru_r)/\partial r) + (\partial u_z/\partial z) = 0 \quad (56)$$

This equation is automatically satisfied if the velocity components are defined through the stream function as:

$$u_r = (1/r)(\partial\psi/\partial z), u_z = -(1/r)(\partial\psi/\partial r) \quad (57)$$

With this definition, each line $\psi = \text{const}$ represents a streamline of the meridional flow in the (r, z) plane. The specific form of the stream function is chosen as follows:

$$\psi(r, z) = Ar^2(1 - r)[\sin(\pi z/H)(1 + 0.6 \sin(2\pi z/H))](1 + 0.4 \exp(-z/0.08)) \quad (58)$$

The first factor, $r^2(1 - r)$ ensures that ψ becomes zero both on the rod surface at $r = r_{rod}$, and on the outer wall at $r = R$, which corresponds to the no-slip condition on solid boundaries. The maximum of this polynomial is reached at $r = 2R/3$, that is, approximately in the middle part of the gap between the rod

and the wall. This position determines the radial coordinate of the center of the main toroidal recirculation cell. The second factor, containing the first and second harmonics in z , $\sin(\pi z/H)(1 + 0.6 \sin(2\pi z/H))$, shifts the maximum of the stream function to the lower third of the reservoir. Numerically, the maximum is reached near $z \approx 0.28H$, which reflects the physical influence of the rotating disk. Through the Kármán layer, the disk creates an intense radial outflow of fluid and forms a downward axial flow along the rod.

The third factor, $\exp(-z/0.08)$ enhances the stream function near the lower endwall, simulating the intensified meridional motion in the Kármán layer of thickness $\delta_K \sim (\nu/\Omega)^{1/2}$, where ν is the kinematic viscosity and Ω is the angular velocity of the rotating disk.

The meridional velocity components are calculated numerically using the central difference scheme:

$$u_r(r, z) = \frac{1}{r} \frac{\psi(r, z+\varepsilon) - \psi(r, z-\varepsilon)}{2\varepsilon} \quad (59)$$

$$u_z(r, z) = -\frac{1}{r} \frac{\psi(r+\varepsilon, z) - \psi(r-\varepsilon, z)}{2\varepsilon}$$

where $\varepsilon = 10^{-4}$ in normalized units. Such a velocity field satisfies the continuity equation with machine precision, since it is constructed as an exact differential of the stream function.

Inside the recirculation cell, the fluid moves along closed toroidal orbits. Near the rotating disk, the fluid is spun up and, under the action of centrifugal force, is thrown toward the wall; it then rises upward along the outer boundary, turns in the upper part of the reservoir, and descends back along the rod. The trajectories are determined by the condition $\psi = \text{const}$, while the local velocity along the orbit is proportional to $|\nabla\psi|/r$. The azimuthal velocity component is specified separately in the form

$$u_\phi(r, z) = \Omega RB[1 - 0.6B] \exp(-z/z_{decay}), \quad (60)$$

where $B = (r - r_{rod})/(R - r_{rod})$ is the dimensionless normalized radial coordinate inside the annular gap between the central rod and the outer wall of the reservoir, r is the current radial position of the flow point, r_{rod} is the radius of the central rod, and R is the inner radius of the outer wall of the reservoir; $z_{decay} = H(0.3 - 0.025\Omega)$ is the characteristic decay scale of the rotational influence along the vertical direction

At $r = r_{rod}$, the no-slip condition $u_\phi = 0$ is satisfied, while at $r = R$ the velocity approaches a constant value specified by the tangential fluid injection. The quadratic radial profile corresponds to Couette flow with a correction for the centrifugal redistribution of angular momentum. At Reynolds numbers $Re = U_s \delta_s/\nu$ of the order of several hundred, the profile acquires a characteristic inflection in the region of maximum shear $\partial u_\phi/\partial r$, located near the radius r_s .

The streamlines are constructed by numerical integration of the system

$$dr/ds = u_r(r, z), dz/ds = u_z(r, z) \quad (61)$$

using the fourth-order Runge-Kutta method with a step size $ds = 0.003$. From each starting point (r_0, z_0) a trajectory of up to 2000 steps is integrated. The integration is terminated when the boundary of the domain is reached or when the streamline closes upon itself:

$$|\delta r|^2 + |\delta z|^2 < 10^{-4} \quad (62)$$

The set of obtained curves forms a structure visually analogous to experimental patterns of meridional flow: a single large toroidal cell with its center located near $r_c \approx 0.3R$, $z_c \approx 0.28H$, densely filled with closed orbits inside and radial trajectories near the periphery.

The vortex (velocity) map in the background displays the normalized field $u_\varphi/u_{\varphi,max}$ where the dark blue color corresponds to an almost zero velocity near the rod and the upper boundary, while the turquoise-green color represents the maximum azimuthal velocity near the outer wall. This map reflects the distribution of the rotational kinetic energy dissipated in the annular shear layer. The viscous dissipation power is given by

$$\varepsilon_{diss} = \nu \left[r \frac{\partial}{\partial r} \left(\frac{u_\varphi}{r} \right) \right]^2 \quad (63)$$

integrated over the volume. The motion of a passive admixture is described by the advection–diffusion equation:

$$\frac{\partial C}{\partial t} + u_r \frac{\partial C}{\partial r} + u_z \frac{\partial C}{\partial z} = D \left[\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial C}{\partial r} \right) + \frac{\partial^2 C}{\partial z^2} \right] \quad (64)$$

where D is the molecular diffusion coefficient and C is the admixture concentration. In the Lagrangian formulation, the trajectory of each particle satisfies the equations

$$dr/dt = u_r(r, z) + \xi_r, dz/dt = u_z(r, z) + \xi_z \quad (65)$$

where ξ_r and ξ_z are Gaussian random increments with variance $\sigma^2 = 2D dt$, modeling molecular diffusion. The integration is performed using the fourth-order Runge–Kutta method with the subsequent addition of the stochastic contribution. Particles are introduced at the upper boundary of the reservoir at $z = H$, $r_0 = r_{rod} + 0.45R$, with a small random spread $\delta r \sim 0.02R$. After injection, they are captured by the meridional circulation and move inside the recirculation cell, gradually dispersing due to diffusion. The characteristic residence time of a particle inside the cell is estimated as $\tau_{cell} \sim H/|u_z|_{max}$, which, for typical parameters, amounts to several seconds. During this time, the diffusive spreading has a scale $\ell_{diff} \sim (D \tau_{cell})^{1/2}$. For $D = 8 \times 10^{-4}$ and $\tau_{cell} \sim 5$ sec, we obtain $\ell_{diff} \sim 0.06R$, which is of the same order as the thickness of the annular shear layer δ_s .

12. Boundary of Influence of the Helical Shell.

The boundary of influence of the helical shell is defined as the region within which the amplitude of the azimuthal mode remains comparable to the intensity of the main swirling flow. Within this zone, the helical structure significantly modifies the distributions of velocity, pressure, and vorticity, whereas outside it the flow gradually returns to a quasi-axisymmetric rotational state.

The velocity field is represented as a superposition of the mean swirling flow and a spatial modal disturbance:

$$\mathbf{u} = \mathbf{u}_0 + \mathbf{u}' \quad (66)$$

Here, $\mathbf{u}_0$ corresponds to the main axisymmetric rotational motion, while $\mathbf{u}'$ describes the helical azimuthal mode, $u'(r, \varphi, z) = A(r, z) \cos(4\varphi - kz)$. The amplitude of the modal disturbance is maximal inside the annular shear layer and decreases with distance from it. The radial distribution of the amplitude is approximated by

$$A(r, z) = A_0(z) \exp \left[- (r - r_0(z))^2 / 2\sigma_s^2 \right], \quad (67)$$

where $r_0(z)$ is the mean radius of the helical shell, and σ_s is the characteristic thickness of the region influenced by the mode. The strongest effect of the helical structure is observed at $r \approx r_0(z)$, where the main velocity gradients and maximum vorticity values are localized. With increasing distance from this region, the modal amplitude rapidly decreases: $A(r, z) \rightarrow 0$. The boundary of influence is defined by the condition under which the energy of the modal disturbance becomes small compared with the energy of the main flow: $|u'|/|u_0| \leq \varepsilon$, where $\varepsilon \ll 1$. Typically, $\varepsilon \sim 0.05 - 0.1$. Then the radius of the influence region is determined by the condition

$$A(r_b, z) = \varepsilon A_{max}(z), \quad (68)$$

from which, for a Gaussian amplitude distribution, one obtains:

$$r_b(z) = r_0(z) + \sigma_s \sqrt{2 \ln(1/\varepsilon)} \quad (69)$$

The obtained surface forms a spatial boundary within which the flow retains the influence of the helical mode. Inside this region, the flow is characterized by pronounced azimuthal nonuniformity:

$$\partial u_\varphi / \partial r \neq 0, \partial p / \partial \varphi \neq 0, \omega_z \neq \text{const.} \quad (70)$$

Within the region of influence, the azimuthal modulation of pressure, the spatial deformation of streamlines, local pressure minima, and increased vorticity concentration are preserved.

Beyond this boundary, the influence of the helical shell rapidly weakens. In this case, the flow gradually returns to the mean swirling motion: $\mathbf{u}(r, \varphi, z) \approx \mathbf{u}_0(r, z)$, the azimuthal pressure gradients decrease, $\partial p / \partial \varphi \rightarrow 0$, and the streamlines become close to concentric circles. Physically, this boundary corresponds to the region where the vortex energy of the helical mode decays. Inside it, the flow remains coupled to the annular shear layer near the stationary rod, whereas outside it the global circulation of the reservoir dominates. Since the helical shell possesses a spatial spiral geometry,

$$\varphi(z) = \varphi_0 + kz, \quad (71)$$

the boundary of its influence also takes the form of a spatial helical surface. This surface is not a cylinder of constant radius and deforms along the reservoir height due to variations in the thickness of the shear layer, the influence of inlet and outlet flows, pressure redistribution, and the gradual decay of vorticity.

Thus, the region influenced by the helical shell represents a spatial annular volume surrounding the stationary rod, within which a coherent helical organization of the flow is maintained. Outside this volume, the helical mode gradually decays, and the flow transitions to a more homogeneous swirling state.

13. Vertical Transformation of the Quadrupole Helical Mode. In the lower part of the reservoir near the rotating disk, the most energetically saturated region of the swirling flow is formed. It is precisely here that the flow receives the maximum angular momentum, as a result of which the circumferential velocity reaches its highest values: $u_\varphi \sim \Omega r$. In this region, an intense annular shear layer develops near the stationary central rod, where the condition $\partial u_\varphi / \partial r \neq 0$ is satisfied.

High velocity gradients lead to an increase in inertial stresses, $\sigma_i \sim \rho(u_s^2/R_c)$, as a result of which the

helical structure in the lower part of the reservoir undergoes pronounced nonlinear deformation. The lobes of the quadrupole mode become elongated, the spatial curvature of the streamlines increases, and the outer surface of the shell begins to experience radial oscillations. In this zone, the flow is characterized by maximum vorticity and the most intense pressure redistribution. Pressure minima are concentrated inside the helical channels, leading to local acceleration of the fluid motion and enhanced spatial swirling.

In the lower part of the reservoir, the spatial structure is characterized by a high amplitude of azimuthal modulation described by expression (1), while the function $A(r, z)$ reaches its maximum at small values of the coordinate z . The intense energy input from the rotating disk leads to the formation of pronounced radial-azimuthal flows that enhance the nonlinear deformation of the helical shell. In this region, the quadrupole mode possesses the maximum spatial curvature and the

strongest deviation from the axisymmetric state. As the distance from the rotating disk increases and the flow moves upward through the reservoir, the intensity of the swirl gradually decreases. Viscous dissipation and redistribution of angular momentum lead to a reduction in the amplitude of the azimuthal mode: $A(r, z) \downarrow$. At the same time, the local vorticity decreases:

$$\omega_z = (1/r)(\partial(ru_\phi)/\partial r). \quad (72)$$

The upper region of the reservoir is characterized by a smoother and more stable geometry of the helical shell. The spatial structure retains the quadrupole symmetry $m = 4$; however, the deformation of the lobes decreases, and the phase lines become smoother. In this zone, the local curvature of the shell decreases, inertial stresses are reduced, and the radial-azimuthal exchange of momentum weakens. The flow gradually transitions to a more relaxed state, close to a stationary coherent helical mode.

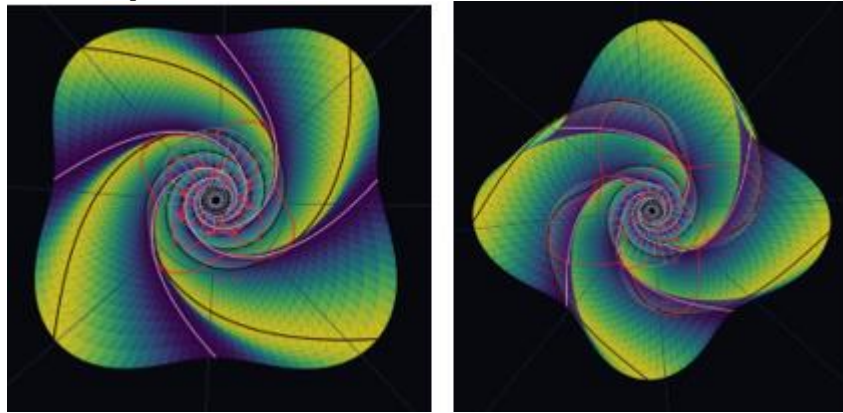


Figure 5. Nonlinear deformation of the quadrupole helical mode in the cross section of the annular swirling layer. Spatial configurations of the azimuthal mode $m = 4$, corresponding to different levels of nonlinear deformation of the helical shell, are shown. The color structure reflects the distribution of swirl intensity and local vorticity, while the spiral lines demonstrate the spatial redistribution of angular momentum inside the deformed annular layer surrounding the stationary central rod.

Since the spatial phase shift $\theta(z) = kz$ (73) is preserved throughout the entire height of the reservoir, the transverse quadrupole structures remain interconnected by a unified helical geometry. However, the intensity of this coupling decreases with increasing distance from the region of maximum energy input. As a result, the lower part of the reservoir corresponds to a regime of strong nonlinear deformation of the shell, whereas the upper region is characterized by a more stable and more symmetric spatial organization of the flow.

Thus, the helical shell is formed in the lower part of the reservoir as an energetically saturated nonlinear structure with a high concentration of angular momentum and intense spatial swirl. Then, as it propagates upward, it gradually loses part of its energy, becomes smoother, and transitions to a more stable spatial state (Fig. 5).

14. Criteria for the Onset and Breakdown of the Mode. The onset of the quadrupole azimuthal mode occurs when the local Reynolds number reaches the critical value $Re_s \geq Re_{s,cr}$. In this region, the flow loses complete axial symmetry, and a stable quadrupole structure with $m = 4$ develops inside the annular vortex layer. The formation of the mode is associated with

the development of an azimuthal instability in the region of maximum radial gradients of the circumferential velocity, $\partial u_\phi / \partial r \neq 0$. With a further increase in the swirl intensity, the quadrupole mode acquires a spatial phase shift along the reservoir height, as a result of which the transverse structures merge into a single helical shell.

Within the range of moderate Reynolds numbers, the helical structure retains its coherence due to the balance between angular momentum input, pressure gradients, and viscous dissipation. In this regime, the flow is characterized by a stable spatial organization and the existence of stationary helical channels for momentum transport. With a further increase in the local Reynolds number, $Re_s \gtrsim 10^4$ the helical shell begins to lose stability. Longitudinal oscillations, local phase shifts, and unsteady deformations of the shell arise within the structure. The spatial coherence is gradually disrupted, after which the shell breaks up into separate unsteady vortex tubes and localized vortex structures.

The breakdown of the shell is accompanied by an intensification of three-dimensional velocity fluctuations, enhanced turbulent mixing, and the appearance of spatially disordered vortex regions. In this regime,

the flow undergoes a transition from an organized helical mode to a complex unsteady swirling flow.

The evolution of the structure with increasing swirl intensity may be represented by the following sequence: axisymmetric cross section $\rightarrow m = 4 \rightarrow$ helical shell $\rightarrow$ precession $\rightarrow$ vortex chaos. Thus, the quadrupole helical mode exists within a limited range of parameters, inside which a balance is maintained between the mechanisms of swirl generation, spatial modulation of the vortex layer, and viscous energy dissipation.

15. Additional Analysis of the Spatial Structure.. In the considered regime, the swirling flow possesses a pronounced spatial organization. The forming helical shell is not an isolated concentrated vortex, but rather a spatially deformed annular layer of angular momentum transport localized around the stationary central rod. As the swirl intensity increases inside the reservoir, stable regions of local accumulation of kinetic energy, enhanced vorticity, and reduced pressure arise. These regions merge into helical channels associated with the quadrupole azimuthal mode.

The spatial geometry of the shell is determined by the phase shift of the transverse modes along the reservoir height. As a consequence, neighboring horizontal cross sections become rotated relative to one another, while the maxima of swirl connect into continuous helical lines. Such an organization of the flow corresponds to a standing helical mode within a confined cylindrical volume, inside which a coherent spatial coupling between the transverse quadrupole structures is maintained.

Inside the helical shell, intense transport of energy and momentum takes place. Centrifugal forces tend to expand the annular vortex layer, whereas pressure gradients and viscous stresses confine the structure to a limited region near the stationary rod. As a result, a dynamic balance is formed between the angular momentum input from the rotating disk and viscous energy dissipation inside the shear layer.

A special role is played by the interaction of the helical shell with secondary toroidal recirculation zones. These structures arise due to pressure redistribution along the reservoir height and lead to the formation of local closed circulation contours. Consequently, a complex system of interconnected vortex structures of different spatial scales is formed inside the reservoir.

The distribution of a passive admixture in the considered flow also acquires a spatially organized character. The injected dye is stretched along the helical channels and forms thin spiral concentration filaments. The transport rate of the admixture is determined not only by the global rotation of the fluid, but also by the local geometry of the azimuthal modes and the secondary recirculation zones.

Of additional interest is the relationship between the observed structure and wave regimes in swirling flows. The spatial organization of the shell resembles a standing-wave configuration in cylindrical resonant systems. The pressure field contains stable azimuthal maxima and minima, while the structure itself possesses a pronounced modal organization and retains coherence within a limited range of flow parameters.

The obtained results make it possible to regard the helical shell as a coherent hydrodynamic structure arising from the loss of complete axial symmetry of the annular shear layer near the stationary central rod. The spatial organization of the flow is determined by the combined action of swirl, viscosity, pressure gradients, and the geometric confinement created by the internal stationary obstacle.

16. Discussion. The obtained results demonstrate that the presence of a stationary central rod radically alters the structure of the swirling flow in a cylindrical reservoir. Instead of forming a continuous axial vortex core, an annular shear layer arises which, at sufficiently large values of the local Reynolds number, becomes a source of azimuthal instability.

A distinctive feature of the considered regime is the formation of a stationary quadrupole mode with $m = 4$. Unlike classical Taylor–Couette vortices, the observed structure is not associated with the formation of periodic annular vortices between rotating cylinders. In the present configuration, a spatial deformation of a hollow vortex shell around a stationary internal obstacle develops. The main transport of angular momentum occurs within a confined annular layer, which loses complete axial symmetry and transitions to a spatially nonuniform state.

The obtained structure possesses several properties of a coherent hydrodynamic mode. It is characterized by spatial phase synchronization of transverse cross sections, a stable pressure distribution, a stationary geometry of the helical shell, an internal force balance, and the existence of stable recirculation zones. The spatial organization of the flow is maintained through the interaction of centrifugal forces, pressure gradients, viscous dissipation, and the continuous input of angular momentum from the rotating disk.

The helical shell may be interpreted as a spatially deformed surface of angular momentum transport localized inside the annular shear layer. At the same time, the structure itself is not an individual concentrated vortex, but rather a modal deformation of the swirling flow within a confined cylindrical volume.

Of particular interest is the relationship between the transverse quadrupole structures and the spatial helical shell. The transverse modes represent horizontal cross sections of a single three-dimensional helical surface, whereas the longitudinal recirculation regions correspond to projections of this spatial structure onto the (r, z) plane. The obtained results show that the helical shell substantially affects the entire hydrodynamic organization of the flow inside the reservoir. The spatial mode induces secondary toroidal recirculation structures, modifies the pressure distribution, and determines the character of admixture transport throughout the fluid volume.

Thus, the considered system demonstrates a transition from an axisymmetric swirling flow to a complex spatially organized modal structure arising from the interaction between rotational motion and an internal stationary obstacle. Moreover, it was observed that the enhancement of admixture concentration near the mean radius of the annular shear layer with increasing azimuthal mode number m is caused by the simultaneous

action of three interconnected mechanisms. First, as m increases ($m = 1, 2, 3, 4$), the number of intersections between the deformed vortex shell and the region $r \approx r_s$ increases, thereby raising the probability of particle residence near the mean radius of the layer. Second, a mechanism of parametric dynamical trapping arises, associated with the fact that azimuthal oscillations of the shell create a periodic forcing on the radial motion of particles. When the resonance condition $m\Omega_{shell} \approx \omega_{inertia}$ is satisfied, radial deviations are amplified in such a way that particles remain near r_s for a longer time. Finally, at sufficiently large values of m , when the condition $m > m_{crit}$ is satisfied, the mechanism of diffusive trapping begins to dominate. In this regime, transverse diffusion is no longer able to transport particles beyond the boundaries of the individual azimuthal cells of the shell, and the admixture becomes localized inside the annular layer. All three mechanisms act coherently and lead to an increasingly strong concentration of the admixture within the main annular shear layer as the azimuthal mode number increases.

17. Conclusion.

This work investigates the spatial organization of swirling fluid flow in a cylindrical reservoir with a rotating disk and a stationary central rod. It is shown that the presence of an internal stationary obstacle leads to the formation of an annular shear layer near the rod surface, where strong radial gradients of azimuthal velocity and localized vorticity concentration arise.

Based on spectral decomposition of the perturbation field into azimuthal modes, it is established that the loss of stability of the annular layer is accompanied by the development of non-axisymmetric spatial modes. The results indicate that the most physically consistent mechanism responsible for the observed four-sector structure is the development of the primary dipole mode $m=2$ followed by nonlinear generation of the second harmonic $m = 4$. As a result, the flow evolves into a mixed modal state $m = 2 + m = 4$, forming a spatial helical shell around the stationary central rod.

It is shown that the quadrupole structure arises as a consequence of nonlinear self-interaction of the dipole mode and redistribution of vorticity within the annular shear layer. The presence of a longitudinal phase shift transforms the transverse azimuthal modes into a unified three-dimensional helical structure extending along the height of the reservoir.

The obtained results demonstrate that the helical shell does not represent an independent concentrated vortex core, but rather a spatially modulated surface of angular momentum transport and vorticity localization surrounding the stationary rod. The stability of this structure is governed by the balance between centrifugal forces, radial pressure gradients, viscous dissipation, and continuous angular momentum input from the rotating disk.

The study further shows that the helical modal structure induces a complex spatial redistribution of velocity, pressure, and vorticity inside the reservoir and leads to the formation of secondary toroidal recirculation zones. The influence region of the helical mode is limited to the domain where the amplitude of azimuthal

perturbations remains comparable to the intensity of the primary swirling flow. Outside this region, the flow gradually returns to a quasi-axisymmetric rotational state.

Analysis of passive scalar transport demonstrates that the motion of the tracer is governed by the geometry of the helical channels and secondary recirculation structures, causing the scalar field to stretch into thin spiral concentration filaments that follow the shape of the helical shell.

Thus, the investigated structure may be regarded as a coherent spatial modal organization of the annular swirling layer inside a confined cylindrical volume with an internal stationary obstacle. The proposed physical and mathematical interpretation may be useful for the analysis of swirling flows in vortex devices, rotor reactors, hydrodynamic mixers, intensive liquid mixing systems, and in studies of spatial modes and instabilities in rotating flows.

18. Limitations of the Model.

The physical and mathematical model presented in this work describes the spatial organization of swirling flow in a cylindrical reservoir with a rotating disk and a stationary central rod based on a modal interpretation of the annular shear layer. The proposed approach combines qualitative spectral analysis, modal decomposition, and phenomenological reconstruction of the helical vortex structure. Nevertheless, the model possesses several important limitations associated both with the adopted approximations and with the absence of a complete three-dimensional stability analysis.

Although the present study includes spectral decomposition of the perturbation field into azimuthal Fourier modes and identifies the dominant contributions of the $m = 2$ and $m = 4$ harmonics, a rigorous eigenvalue analysis of the linearized Navier–Stokes operator was not performed. In particular, the complete spectrum of unstable modes, their exact growth rates, and critical transition thresholds were not explicitly calculated. Therefore, the proposed modal selection mechanism should be regarded as a physically motivated spectral model rather than a strict solution of the hydrodynamic stability problem.

In the present work, the quadrupole spatial structure is interpreted primarily as a nonlinear consequence of dipole instability and its second harmonic. However, the relative contributions of centrifugal instability, Kelvin–Helmholtz-type instability, and nonlinear mode interaction were not quantitatively separated. A complete stability analysis would require direct computation of the global eigenmodes of the swirling flow.

Another limitation is associated with the absence of direct numerical simulation of the fully unsteady three-dimensional flow using DNS or LES approaches. The presented helical shells correspond to modal reconstructions and conceptual representations of the annular vortex layer rather than fully resolved turbulent flow fields. Consequently, small-scale turbulent fluctuations and unsteady vortex interactions are not captured within the framework of the present model.

The study also lacks direct experimental validation using PIV measurements, tomographic visualiza-

tion, laser diagnostics, or other flow measurement techniques. Therefore, the proposed spatial structures should presently be regarded as physically consistent theoretical interpretations of the modal organization of swirling flow.

An additional simplification is associated with the phenomenological representation of the modal amplitude in the form of a Gaussian distribution:

$$A(r, z) = A_0(z) \exp \left[- (r - r_0(z))^2 / 2\sigma_s^2 \right],$$

which is introduced to describe the localization region of the helical structure. In reality, the amplitude distribution may depend on boundary conditions, reservoir geometry, angular momentum injection intensity, turbulence level, and nonlinear vortex interactions.

The model also neglects possible effects associated with the free surface, cavitation, unsteady inflow conditions, density stratification, thermal inhomogeneity, and fluid compressibility. The analysis is restricted to the case of an incompressible homogeneous fluid with a statistically stationary mean swirl regime.

Despite these limitations, the proposed interpretation provides a physically consistent description of the mechanism responsible for the loss of axial symmetry in the annular shear layer, the nonlinear interaction of azimuthal modes, and the formation of coherent helical vortex structures around the stationary central rod. The obtained results may serve as a basis for future global stability analysis, fully three-dimensional numerical simulations, and experimental investigations of spatial modes in swirling flows.

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MEDICAL SCIENCES

THE ASSOCIATION BETWEEN VITAMIN D DEFICIENCY AND COMMUNITY-ACQUIRED PNEUMONIA

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Abstract

Emerging evidence has shown that vitamin D deficiency may be related with community-acquired pneumonia (CAP), but individually published studies showed inconclusive results. The aim of this study was to quantitatively summarize the association between vitamin D and the CAP.

We conducted this meta-analysis through a systematic literature search of PubMed, Medline, and EMBASE up to 31 September 2018 with the following keywords 'vitamin D' or 'cholecalciferol' or '25-hydroxyvitamin D' or '25(OH)D' in combination with 'community-acquired pneumonia' or 'CAP' or 'pneumonia' with no limitations. This meta-analysis was performed following the guidelines of Meta-analysis of Observational Studies in Epidemiology. The association between vitamin D levels and CAP were measured as odds ratio (OR) and weighted mean difference (WMD). Results were combined using a random-effect or a fix-effect meta-analysis, and sensitivity analyses were conducted to explore potential factors.

Eight observational studies involving 20,966 subjects were included. In this meta-analysis, CAP patients with vitamin D deficiency (serum 25(OH)D levels <20 ng/mL) experienced a significantly increased risk of CAP (odds ratio (OR) = 1.64, 95% confidence intervals (CI): 1.00, 2.67), and an obvious decrease of -5.63 ng/mL (95% CI: -9.11, -2.14) in serum vitamin D was demonstrated in CAP patients. Sensitivity analysis showed that exclusion of any single study did not materially alter the overall combined effect.

The evidence from this meta-analysis indicates an association between vitamin D deficiency and an increased risk of CAP patients. However, well-designed trials are required to determine the explicit effect of vitamin D supplementation.

Keywords: community-acquired pneumonia, meta-analysis, pneumonia, vitamin D

Introduction

Community-acquired pneumonia (CAP) is an infectious inflammation of lung parenchyma (including lung interstitium) occurring outside hospitals, which is one of the common infectious diseases threatening human health and is a non-negligible problem during prevention and control of public health emergencies. The prevalence and incidence rates of CAP are linked to increasing age, especially among the elderly above age 65. The patients of CAP in the US was estimated to be 5.6 million every year, among which about 1.1 million patients that needed hospitalization (1). The average in-hospital duration of CAP patients was 1 week in the US, the 30-day mortality rate was above 20%, and the mortality rate within 1 year of CAP patients after discharge was about 30% (2-4). Besides, the clinical and economic burden of CAP is high over the world. For example, the costs of CAP in the Europe exceeded 10 billion Euro annually, with inpatient care accounting 5.7 billion, outpatient care 0.5 billion and drugs 0.2 billion (5-7). About 60% of CAP patients were treated outpatient and the costs were low, however, the 40% of CAP

patients admitted were faced with high mortality rate and medical costs, and the death rates of CAP patients during in-hospital treatment were far higher than other causes of death and ranked second among all in-hospital patients (8). With the developing of aging population recent decades, the hospitalization rate and death rate of CAP patients above age 65 are rising (9).

Recently, much attention has been paid to the role of vitamin D in host defense against infection. Apart from its classic function in calcium-phosphate homeostasis, vitamin D has pleiotropic immunomodulatory properties. It is reported that the vitamin D plays an important role in the innate immune response, particularly by increasing the production of antimicrobial peptides (B-defensing, cathelicidin) (10). Furthermore, vitamin D has been found to be of great effect on the activity of the adaptive immune system (10). And several studies have shown an association between vitamin D deficiency (VDD) and increased the susceptibility to respiratory tract infections (11-15). One study has investigated the relationship between 25-hydroxyvitamin D (25-(OH) D) levels and clinical outcome in CAP adults

(16). Berry et al found that vitamin D levels were associated with the incidence rate of respiratory tract infections, or namely the incidence rate of respiratory tract infections dropped by 7% when the serum 25-(OH) D3 level increased by 10nmol/L (12). Another retrospective study showed the possibility of hospitalization due to CAP rose when the serum 25-(OH) D3 level was < 37nmol/L (17). These studies all imply VDD may be the potent cause of CAP. However, Remmelts et al found an opposite conclusion that vitamin D did not reduce the incidence rate of pneumonia, and vitamin D supplementation even would raise the incidence of pneumonia without the medication of steroid hormones (18). When 162 respiratory tract infection (RTI) adults were randomly given 12 weeks of vitamin D (2000U/d) or placebo, the serum vitamin D levels in the test group significantly rose, but the RTI was not significantly improved (19). Another study in Canada showed the vitamin D level was not significantly related with the hospitalization of RTI children(20).

Up to present, there is more and more evidence indicating the association between vitamin D deficiency with community-acquired pneumonia. But these studies researching on the relationship of vitamin D and community-acquired pneumonia showed inconclusive results. Hence, we performed this meta-analysis to quantitatively summarize the association between vitamin D and the CAP, in order to provide some scientific suggestions for prevention of CAP.

2. Methods

2.1. Search strategy and selection criteria

Literatures on PubMed, Medline, Medline, Cochrane and EMBASE were systematically searched up till 31 September 2018 for relevant articles using the following keywords 'vitamin D' or 'cholecalciferol' or '25-hydroxyvitamin D' or '25(OH)D' in combination with 'community-acquired pneumonia' or 'CAP' or 'pneumonia' with no limitations. We also manually searched all eligible original articles, reviews and other relevant articles. And we contacted relevant authors by emails if necessary. This meta-analysis was performed following the guidelines for Meta-analysis of Observational Studies in Epidemiology (MOOSE) (21). No ethical approval is needed, for the reason that this study is a meta-analysis.

2.2. Inclusion and exclusion criteria

Original articles exploring the association between serum vitamin D status and CAP were reviewed and selected following these inclusion criteria:

- 1. The study population was human;
- 2. Serum was sampled for assays of vitamin D levels;
- 3. CAP was the outcome and the control group consisted of people without CAP;
- 4. The sample size, the odd ratios (ORs) and their corresponding 95% confidence intervals (CIs) of the study were available;
- 5. Vitamin D deficiency (VDD), vitamin D insufficiency (VDI) and severe vitamin D deficiency (SVDD) were defined as 10 to 20ng/mL, 20 to 30ng/mL, and <10ng/mL 25(OH)D, respectively (22);

- 6. Studies published in English; Animal experiments, chemistry, cell-line studies and editorials, review studies, commentaries, opinions and case reports were excluded.

Two authors independently assessed all literature searches and obtained full articles for all citations meeting the selection criteria. Final inclusion or exclusion decisions were made after reading the full articles carefully. A third author was participated in the literature searches to get a consensus when disagreement disappeared.

2.3. Quality assessment

In order to assess the quality of studies in this meta-analysis, the predefined methodological quality assessment criteria for observational studies was used. We assessed the quality of these studies with a checklist, adapted from Taggart et al (23), using participants selection, comparability of groups at baseline, and how the diagnosis of CAP was made and according to what definition (see Table S1, Supplemental Content, which illustrates the Quality assessment of observational studies). We excluded any study that did not score in any item or a total score <7 out of 10 maximal points (24). We used the design and sample size of studies to score for heterogeneity. Two authors (LLQ and YFZ) were responsibility for the extraction data independently, and the third author (BAL) took part in to reach a consensus when any differences occurred.

2.4. Data extraction

Data were extracted independently by two authors, and cross-checked by a third author using a standardized data extraction form. This information of each study was extracted carefully: the name of first author, publication year, location, study design, sample size, vitamin D assay method, vitamin D concentration, prevalence of vitamin D deficiency, and potential confounding factors included in the adjustments. In case of relevant data missing, the main authors were contacted for more information.

2.5. Statistical analysis

This meta-analysis was performed on RevMan 5.3 (Cochrane Collaboration, London, UK). The relationship of vitamin D levels and CAP were evaluated as ORs and weighted mean difference (WMD). If the OR and 95% CI were not available, the 2×2 tables were used to obtain the value of OR and 95%CI. Data reported as median and range was converted to mean and standard deviation (SD) (25).

Forest plots were used to evaluate the pooled estimates and corresponding 95% CIs for each study. The I^2 statistical test was performed to assess the heterogeneity in this meta-analysis. According to the I^2 statistical test, there were low ($I^2 < 25\%$), moderate (near 50%) and high heterogeneity ($I^2 > 75\%$). In case of heterogeneity ($I^2 > 50\%$), a random-effects model was used; otherwise, the fixed-effects model was used in this meta-analysis. The sensitivity analyses were conducted to explore potential factors that may introduce heterogeneity into the results, and to investigate the effect of a single article on the overall risk estimated by removing one article in each turn. In this study, the $P < .05$ was considered significant. Publication bias was also conducted to explore potential factors by the funnel plots.

3. Results

3.1. Description of studies

A total of 623 articles were initially identified through the systematic literature search, and 47 full articles were read after screening the abstracts. Of these, 7 reviews and 22 studies not meeting the inclusion criteria were excluded. In addition, 6 studies were excluded for the reason of insufficient data. Finally, 8 articles (26-33) were included after the strict screening.

According to the predefined methodological quality assessment criteria for observational studies (23-24), the quality scores of these studies ranged from 8 to 10, indicating all the included studies were of high quality.

Among the 8 articles, there were 4 case-control studies, 2 retrospective studies, one cross-sectional study and one prospective study. And these studies were published from 2010 to 2018 and reflected 6 countries. Four assay techniques were used to measure vitamin D levels. Among these included studies, 6 studies explored the relationship between VDD and CAP (27-30, 32-33) 5 studies researched the relationship between VDI and CAP (26,28,29,32,33), and 5 other studies discussed the relationship between SVDD and CAP (28,30-33). Meanwhile, only 6 of the 8 studies explored the mean difference in serum vitamin D levels between CAP and non-CAP(26,29-33).

The diversities of participant characteristics were considerable in these studies. A total of 20,966 participants were consisted of various ethnicities. Age ranged from 3 days to 94 years old, and the prevalence of VDD, if provided by studies, ranged from 33.9% to 65.1%. Seven of the 8 studies were conducted in adjustments of age, BMI, gender, smoking and other factors.

3.2. The relationships between vitamin D status and the risk of CAP

Random effect model showed that the association between vitamin D deficiency (VDD) and CAP was significant with high heterogeneity (OR=1.64, 95%CI: 1.00, 2.67, $I^2=89\%$). Besides, random-effects meta-analysis revealed the association with CAP was not significant for vitamin D insufficiency (VDI), with high heterogeneity (OR=1.37, 95% CI: 0.81, 2.32, $I^2=88\%$) (Fig. 3), and significant for severe vitamin D deficiency (SVDD), with high heterogeneity (OR=6.65, 95%CI: 2.58, 17.15, $I^2=90\%$).

The comparison of mean difference between CAP group and non-CAP group is Based on 6 studies, the pooled effect was -5.63 ng/mL (95% CI: $-9.11, -2.14$) with high heterogeneity ($I^2=95\%$, $P<.01$), which showed that there was statistically significant difference in vitamin D levels between CAP group and non-CAP group.

3.3. Sensitivity analysis

Sensitivity analyses were conducted to examine the potential sources of heterogeneity in this meta-analysis. In the results of the WMD, Li's study conducted in China (33) was responsible for most of the heterogeneity in this meta-analysis. After excluding this study, the heterogeneity was down to 75% and the WMD was -4.56 (95% CI: $-6.40, -2.71$). Further exclusion of any single study did not alter the overall combined relative risk, and each outcome had statistical significance. And

Quraishi study (28)¹ conducted in Brazil was responsible for most of the heterogeneity in the result of the ORs in this meta-analysis (OR=1.97, 95% CI: 1.38, 2.81, $I^2=61\%$). Besides, there were no obvious changes in the pooled ORs as the results of the exclusion of any other single study.

3.4. Publication bias

No obvious publication bias was observed in the funnel plots of this meta-analysis (see Figure S1, Supplementary Content, which illustrates the publication bias in this meta-analysis).

4. Discussion

This is the first meta-analysis on the relationship between serum vitamin D status and CAP among people. The results of 8 observational studies provide strong evidence that serum 25(OH)D level is associated with CAP. Both the results of the pooled ORs and the pooled effect of WMD showed that the serum 25(OH)D levels had a relationship with CAP. VDD experienced a significantly increased risk of CAP (OR=1.64, 95%CI: 1.00, 2.67). People with CAP, compared to the control, were with the decreased level of vitamin D by 4.56 ng/mL . Considering the prevalence of vitamin D deficiency among humans, this result may provide some scientific suggestions for prevention of CAP.

According to the results of quality assessment, studies included in this meta-analysis were with high quality. Besides, there was no obvious publication bias after the analysis of funnel plots. The results of sensitivity analyses implied 2 studies probably contributed to the heterogeneity (28,30). After these 2 studies were excluded, low heterogeneity was found. Other heterogeneity might result from different vitamin D measuring methods, different sample time, and the differences among the study populations. Hence, more studies are needed to give full proof.

Vitamin D plays an important role in the CAP. As we known, the cause of CAP is associated with both pathogen infection and immune dysfunction. Vitamin D could considerably exert immune functions, so the level of vitamin D may be a susceptible factor of CAP. So far, the relationship between VD and CAP has been extensively studied. As reported by the US Centers for Disease Control and Prevention (CDC), when newborns with low vitamin D in vivo grow up to 1 year old, they have 6 times higher risks of suffering lung infections than infants with normal vitamin D levels (934). Another random control-case study showed when 1- to 36-month-old pneumonia infants orally took a single high-dose of vitamin D3 (100,000 IU), recurrence was basically not found within 3 months (935).

Vitamin D may play two roles in the occurrence of CAP. 1) Vitamin D takes effect through the binding between its activated form 1, 25-(OH)2D3 and the vitamin D receptor (VDR). VDR can stimulate the expression of antibacterial peptides that resist bacterial and viral infections (36). VDD causes the reduction of VDR level in vivo and thereby the denaturation, cornification and proliferation of respiratory tract mucous membrane epithelia, damaging their clearance function and the accumulation of non-neutralized proinflammatory media; consequently, the inflammatory reactions could not be controlled, leading to injured pulmonary tissues and

blocked gas exchange. 2) Recent studies have confirmed the very important immunomodulatory functions that vitamin D could directly regulate the human inherent immunity and adaptive immunity, and which is closely related with respiratory infectious diseases, such as tuberculosis and CAP (37). Vitamin D levels are significantly downregulated in critically ill patients with acute severe pneumonia or sepsis and are correlated with prognosis (31,38). In case of pulmonary infection, the pulmonary endothelial cells can convert the inactive vitamin D into its active form, and stimulate the expression of antibacterial peptides, thereby resisting infection (39). Moreover, vitamin D deficiency is directly correlated with lung function injuries and is one independent risk factor of pneumonia (40). Thus, vitamin D level affects not only the occurrence of lung diseases, but also the severity of CAP. Supplement with vitamin D might be able to reduce the occurrence and the severity of CAP.

There have a few limitations in this study. First, different methods were used to assess vitamin D levels. Second, the relationships from this meta-analysis between vitamin D and CAP might be affected by confounding factors, such as race, age and body mass index. Third, only published articles were included. Finally, vitamin D levels are still affected by the unapproved immunomodulatory reference intervals, season, sunlight, and races. Thus, stricter and normalized double-blind large-size studies are still needed.

5. Conclusions

The evidence presented here indicates an association between VDD and an increased risk of CAP, as person with $< 20\text{ ng/mL}$ serum vitamin D is under increased risk of CAP (OR=1.64, 95%CI: 1.00, 2.67). However, more evidence is needed to better understand the effect of vitamin D on the CAP, and well-designed trials are required to determine the explicit effect of vitamin D supplementation. Therefore, people at risk of VDD and determining how to supplement vitamin D could be considered in the future.

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VITAMIN D AND PREVENTION OF VIRAL INFECTIONS**Shkiryak A.***CEO and chief medical officer “Shkiryak Clinic”**Ukraine**Neurosurgeon**MD, MsSc**ORCID: <https://orcid.org/0000-0002-2282-8285>***Khanenko S.***“Shkiryak Clinic”**Ukraine**Family doctor**MD, MBA**ORCID: <https://orcid.org/0009-0000-4237-1158>**<https://doi.org/10.5281/zenodo.20186449>***Abstract**

Viral infections have been a cause of mortality for several centuries and continue to endanger the lives of many, specifically of the younger population. Vitamin D has long been recognized as a crucial element to the skeletal system in the human body. Recent evidence has indicated that vitamin D also plays an essential role in the immune response against viral infections and suggested that vitamin D deficiency increases susceptibility to viral infections as well as the risk of recurrent infections. For instance, low serum vitamin D levels were linked to increased occurrence of high burdens viral diseases such as hepatitis, influenza, Covid-19, and AIDS. As immune cells in infected patients are responsive to the ameliorative effects of vitamin D, the beneficial effects of supplementing vitamin D-deficient individuals with an infectious disease may extend beyond the impact on bone and calcium homeostasis. Even though numerous studies have highlighted the effect of vitamin D on the immune cells, vitamin D's antiviral mechanism has not been fully established. This paper reviews the recent mechanisms by which vitamin D regulates the immune system, both innate and adaptive systems, and reflects on the link between serum vitamin D levels and viral infections.

Keywords: vitamin D, deficiency, hepatitis, Influenza, Covid-19, AIDS

Introduction

Viruses are entities that can only replicate within a host cell and can infect a variety of organisms, ranging from single-cell bacteria to mammals. A complete viral particle or virion is made of three main structures: (1) a core containing genetic material (DNA/RNA) packed with basic proteins known as nucleoproteins, (2) a protein coat known as the capsid that encases and protects the genetic material, and (3), in some viruses, a lipid bilayer surrounds the capsid, enveloping the viral capsid (1). Understanding the structure and the functionality of viruses is crucial for the development of treatments against viral diseases. One of the approaches used to develop treatments is to study how the human immune system reacts to a viral infection.

Studies have shown that Vitamin D (Calciferol) plays a multitude of biological roles in the human body. Vitamin D Receptors (VDRs) can be found in nearly all cells of the body and many sites of the genome (2). For a century, the link between vitamin D deficiency and susceptibility to various pathogens has been suggested, with the early observation that children with nutritional rickets were more prone to respiratory tract infections, leading to the coining of the phrase “rachitic lung” (3). In the last two decades, epidemiologic studies have demonstrated strong associations between seasonal variations in vitamin D levels and the incidence of various infectious diseases, which include septic shock (4), respiratory infection (5), and influenza (5, 6).

VDR and 1 α -hydroxylase, the enzyme necessary for the conversion of vitamin D into its active form,

have been found on a variety of immune cells, including circulating mononuclear cells (7,8), indicating that vitamin D serves a significant role in evoking an immune response against the invading pathogen (9). This discovery has revolutionized the field of vitamin D immunology. Additionally, studies have shown that vitamin D has a critical role in different physiological diseases. Furthermore, vitamin D deficiency can be linked to chronic conditions, including calcium metabolism disorders, cardiovascular disorders, autoimmune disorders as well as cancer, pertaining to both the development and severity of disease (10). Various studies have been done to link vitamin D with the function of the immune system, specifically those related to autoimmunity. Several studies have shown that vitamin D is involved in the expression regulation of specific endogenous antimicrobial peptides in immune cells (11, 12). In this review, we will discuss the immune-modulatory effects of vitamin D in relation to viral infections and will summarize the recent work done on this topic.

Vitamin D Synthesis and Immune Modulation**2.1. Synthesis of Vitamin D**

Vitamin D enters the body through dietary consumption (about 20% of vitamin D₃) or is synthesized by the skin (80%) from 7-dihydro-cholesterol after exposure to type B ultraviolet (UVB) which varies seasonally. A representative population study done on the European population showed that about 17.7% of Europeans exhibited vitamin D deficiency during the winter months while the percentage fell to 8.3% during the summer months (13). The UVB rays from sunlight convert 7-dihydro-cholesterol to pre-vitamin D₃, which then

rapidly converts to vitamin D₃ (cholecalciferol). After that, vitamin D₃ is biologically activated by hydroxylation in the liver carried out by enzymes cytochrome P450 2R1 (CYP2R1) and cytochrome P450 27 (CYP27A1) converting to 25 hydroxyvitamin D₃ (25(OH)D₃).

The renal 25-hydroxyvitamin D₃-1 alpha-hydroxylase (CYP27B1) activates the hydroxylation of 25-(OH)D₃ in the mitochondria of kidney tissue to produce 1,25-(OH)₂D₃ (calcitriol), the active form of vitamin D₃. The synthesis and activity CYP27B1 is usually regulated by the fibroblast growth factor 23 (FGF-23) (14). Once activated, the vitamin D binds to different VDRs on different cells where it can activate transcription of different genes, thus exerting a hormone-like effect (2,15,16). Other than skin, vitamin D can also be acquired through diet. Foods rich in vitamins D₃ and D₂ are processed in the digestive tract; then, the liberated vitamin D is transported to the liver via human serum vitamin D-binding protein (DBP). After this point, the process of conversion follows the previous pathway to the liver (15). Vitamin D is regulated by the enzyme CYP24A1 that catabolizes excess 25(OH)D₃, a metabolite of vitamin D, to calcitroic acid, which is excreted through bile (17).

2.2. Vitamin D and Endocrine Function

Vitamin D is a versatile molecule that is involved in many different processes in the human body. As discussed earlier, vitamin D plays an autocrine role where it impacts gene transcription; however, vitamin D also has endocrine functions, the primary being regulation of calcium (9). Specifically, vitamin D is crucial for the absorption of calcium from food. Calcium can be transported from the digestive tract in a paracellular or transcellular manner. Paracellular movement of calcium is passive, but the transcellular movement is regulated by the activated form of vitamin D which is then transported to the liver (18). Apart from calcium homeostasis, vitamin D is also involved in other functions such as maintenance of muscle function, prevention from cancer and cardiovascular diseases (18).

2.3. Vitamin D and Innate Immunity

Innate immunity is the first line of defense against foreign entities by the immune system. In recent years, studies have indicated that vitamin D also plays an essential role in the immune system, providing protection against several infections as well as regulating the workings of the immune system (19,20,21). It has been observed that vitamin D plays a critical role in the function of monocyte. The link between monocytes and vitamin D can be made by the enzyme CYP27B1 (22,23). Monocytes exert their immune reaction by phagocytosing the foreign body and using Toll-Like Receptors (TLRs) and other classes of pattern recognition receptors to recognize the foreign entity. Some gathered evidence suggested that there is amplification in the CYP27B1 activity when this event occurs (10). This amplification indicates that there is an increase in the locally produced 1,25(OH)₂D, which binds to the endogenous VDR and controls gene expression in monocytes (24). An increase in the transcription of the gene that codes for an antibiotic protein LL37, which is the active form of an antimicrobial peptide named cathelicidin, is observed (11,25,26). An increase in the level

of LL37 shows enhanced function of monocytes, thereby indicating that vitamin D enhances the activity of monocytes, and the insufficiency of vitamin D can have a negative impact on the potency of monocytes (18,27). Other evidence suggests that Calcitriol could inhibit inflammatory T cell cytokines such as IL-2 and IL-17 and toll-like receptors present on monocytes (28,29). High doses of calcitriol supplementation in healthy human subjects (1 µg twice per day for 7 days) leads to a dramatic reduction in the levels of pro-inflammatory cytokine IL-6 secreted by peripheral mononuclear cells (30). All these effects likely combine and result in the induction of potential regulatory T cells, which are important for regulating immune responses and for the development of autoreactivity (31).

In severe infections, the number of innate granulocytic cells, such as neutrophils, increases dramatically. Early studies suggested that neutrophils are the main source of cathelicidin (32). Recent studies contradicted this finding; one study showed evidence that, despite the expression of VDR on neutrophilic granulocytes, they do not seem to exhibit any CYP27B1 activity that would enable them to convert 25(OH)D into the bioactive form, which is necessary to initiate cathelicidin gene expression (33). Nevertheless, serum 25(OH)D levels were found to be significantly lower in critically ill septic patients. This can be associated with decreased concentrations of the antimicrobial protein cathelicidin (34). This finding strengthens the theory that vitamin D status affects antimicrobial protein levels and can be crucial in infection control.

Besides fighting directly against microbes, monocytes and APCs, in particular, dendritic cells (DC), are important targets for the immune-modulatory effects of vitamin D. The APC play an essential role in the activation of the adaptive immune response, as they are involved in the presentation of the foreign antigens to the T and B cells and are capable of regulating them by either immunogenic or tolerogenic signals through cytokines and expression of co-stimulatory molecules (29). Various studies have demonstrated that vitamin D and its metabolites can alter the function and morphology of DC to induce a more tolerogenic, immature state (19,35,36,37).

2.4. Vitamin D and Adaptive Immunity

Early studies investigating the effects of vitamin D on human adaptive immune cells showed that the expression of the nuclear VDR, as well as vitamin D-activating enzymes, was observed in both Band T cells (38). In T cells, vitamin D acts to reduce the production of cytokine IL-12, an important cytokine for T cell proliferation. Reduction in the production of IL-12 reduces the production of IFN-γ and IL-2. IFN-γ and IL-2 are crucial cytokines for the recruitment of T-cells as well as their proliferation (39). Vitamin D also inhibits the T cells from differentiating in Th1 and Th17 cells, which exert their effect on intracellular pathogens and are pro-inflammatory (40). Vitamin D also has an inhibitory effect on B cells. While it is not studied deeply, it is known to inhibit the proliferation of B cells, differentiation of B cells to plasma cells, secretion of immunoglobulins, and formation of memory cells as well as induce apoptosis in B cells (41). During resting state,

VDR expression by the T and B cells is very low; however, upon activation and proliferation, a significant up-regulation of VDR expression in T and B cells is observed, allowing regulation of nearly 500 vitamin D responsive genes that affect the differentiation and proliferation of these cells (41,42).

When combined, these results suggest that vitamin D may regulate not only the innate but also the adaptive immune system. Vitamin D supplementation could possibly provide a safe and practical form of therapy in the future to support immune tolerance in autoimmune diseases or following transplantation (42).

3. Evidence for Vitamin D Influence on Different Viral Infections

Vitamin D plays an integral role in regulating the immune system. It has been shown in earlier studies that vitamin D levels correspond to the degree of the immune response against viral infections. Vitamin D is known to mediate the innate response by modulating the activity at TLRs, which are common to most immune cells, including macrophages, monocytes, and epithelial cells. Thus, serum levels of vitamin D can be linked to the likelihood of developing and recurrence of viral infections.

3.1. Vitamin D and Rhinovirus

Human Rhinovirus (HRV) is the most common cause of upper respiratory tract infection (URI), which, in turn, is the most frequently occurring acute infection in the industrialized world, with estimates of about two to three episodes per year in adults, and five to seven episodes per year in children (43,44). HRV infection leads to considerable economic burdens in terms of medical visits and school and works absenteeism (45,46). Nevertheless, only one study has investigated the effect of vitamin D on rhinovirus infection (47). Schneider et al. treated primary human bronchial epithelial cells (hBECs) with 25(OH)D or 1,25(OH)₂D and subsequently infected the cells with RV-16. They reported that incubation of the cells with vitamin D metabolites did not effect on RV-16 replication. However, incubation with vitamin D enhanced the secretion of pro-inflammatory chemokines CXCL8 and CXCL10, both in the presence and absence of rhinovirus infection. These chemokines are involved in the recruitment of immune cells such as macrophages, neutrophils, and T-cells to the infection site, and thus could act as an effector mechanism as to how vitamin D alters the anti-viral response to HRV infection.

3.2. Vitamin D and Influenza Viruses

One of the most common types of viral infections are those that affect the respiratory system. Respiratory viral infections lay a massive burden as they are one of the main causes of infant death across the globe. One of the approaches to prevent this problem is to vaccinate infants; however, this is only successful in 60% of all cases, depending on the influenza strain (48,49). Not only infants but adults also bear the burden of the disease. Influenza can be lethal for the elderly, adults with co-morbidities, and obese adults (50). Since influenza infections can have detrimental consequences and the vaccine does not have a satisfactory success rate, researchers are now looking at other preventative measures that can be taken against influenza infections.

Previous work on adults who are affected by influenza viruses has shown that they also exhibit a higher incidence of hypovitaminosis due to factors that affect vitamin D metabolism such as the efficiency of skin at synthesizing vitamin D or reduced renal production of the active form of vitamin D, 1,25(OH)₂D (50). An observational study done between 1980 and 2000 in Norway found that influenza-related mortality during the colder season was linked to the low level of vitamin D among people (51). An observational study conducted on school children investigated the effects of vitamin D supplementation in the prevention of influenza A infection during the winter season when the incidence of flu is much higher. They found that, in the group of children who received a placebo, the number of children infected (18.6%) was almost twice as high as in the group of children who had received the actual supplementation (10.8%) (13).

While there are studies that demonstrate that restoration of normal vitamin D levels can provide better protection against influenza virus infection, a significant number of studies suggest that there is no correlation between vitamin D levels and the prevention of viral infections in the case of influenza virus. A study was carried out on 1641 children with influenza infection, where 177 children were given vitamin D supplements (14,000 IU/wk for eight months), and 209 children were given a placebo. This study is done regarding the correlation between vitamin D and respiratory infections, concluding that vitamin D had reduced non-influenza respiratory viral infection; however, no decrease had been documented with influenza respiratory viral infection (49). To study the effect of vitamin D on innate immune response against the influenza strain H9N2, found commonly in turkeys, research was conducted on epithelial cells, which showed that treatment using calcitriol has negative effects on the immune response against the H9N2 virus, specifically during the later stage of the disease. An increase in the activity of VDR due to high levels of calcitriol results in pro-inflammatory response, which has adverse effects on the disease stage (52). Another study suggests that vitamin D supplementation did not show help in preventing the influenza infection and rather, surprisingly found that supplementation made the disease last longer compared to duration observed in patients who received a placebo (53).

Some studies have also looked into the effect of vitamin D on the efficacy of immunization against influenza viruses. Some works of research have shown a positive link between vitamin D levels and the effectiveness of vaccines. A study conducted on the efficacy of vaccines based on vitamin D levels, and it was found that the depletion of vitamin D to normal levels shows a better immunological response to the vaccine (54). On the other hand, some studies have shown that vitamin D supplementation can reduce the efficacy of a vaccine. A study performed on 135 children, who were vaccinated with live attenuated influenza vaccine (LAIV) or inactivated influenza vaccine (IIV), showed that lower levels of vitamin D demonstrated better response to the vaccines (55).

Considering all the above-detailed studies, there are mixed findings that correlate vitamin D levels with

prevention from influenza infections. Some demonstrate that vitamin D levels are helpful against influenza infections while others state that there are no effects and, in some cases, a negative correlation is seen. This indicates that there might be other mechanisms involved in regulating the immune response against influenza infections that are yet to be studied.

3.3. Vitamin D and Respiratory Syncytial Virus

Respiratory syncytial virus (RSV) is the major cause of bronchiolitis in one-year-old infants, with nearly all children exhibiting serologic evidence for infection with the virus by the age of 2–3 years (56,57). Studies have demonstrated that vitamin D deficiency can be linked to RSV susceptibility, with low concentrations of 25(OH)D in cord blood plasma related to RSV incidence in the first year of life (58). In addition, studies have shown that single-nucleotide polymorphisms in the VDR vitamin D-binding protein can be associated with a genetic predisposition to RSV bronchiolitis (58,59).

On the other hand, Hansdottir et al. have shown that infecting human tracheobronchial epithelial (hTBE) cells with RSV decreases I κ B α , due to RSV-induced degradation, whilst, treating the cell with 1,25(OH) $_2$ D before RSV infection, increases the expression of the NF- κ B inhibitor I κ B α [60]. In addition, they showed that the increase in I κ B α results in NF- κ B remaining inactive in the cell, which, in turn, prevents the translocation of NF- κ B into the nucleus and subsequent binding to DNA promoter regions, which will eventually lead to inhibition of IFN- β and CXCL10 secretion which is driven by NF- κ B. Furthermore, Hansdottir and his colleagues showed evidence that treatment with 1,25(OH) $_2$ D resulted in decreased levels of human myxovirus resistance protein 1 (MxA) and interferon-stimulated genes 15. Even though, treating the hTBE cells with 1,25(OH) $_2$ D reduced the production of important antiviral components responding to RSV infection (IFN- β , CXCL10, MxA, and ISG15), viral replication and viral load did not increase. Thus, through increasing I κ B α levels, vitamin D is able to decrease the inflammatory response to RSV infection while maintaining the antiviral state and without having adverse effects on viral load. This suggests that vitamin D plays a potential role in reducing immunopathology, which is essential in reducing the disease severity and consequently in reducing the morbidity and mortality from this common infection.

Studies have shown that antimicrobial peptides LL37 and β -defensin 2 have antiviral activity against RSV infection via blocking the cellular entry of the virus and preventing the epithelial cell death induced by the virus, which leads to inhibiting the production of new infectious particles and, ultimately, diminishing the spread of the virus in the host (61,62).

3.4. Vitamin D and Dengue Virus

Dengue virus (DENV) is a highly endemic infectious disease of tropical countries and is rapidly becoming a global burden. Dengue fever is a mosquito-borne tropical disease caused by the dengue virus. Severe dengue disease can be linked with high viral loads and overproduction of pro-inflammatory cytokines, suggesting dysregulation in the mechanisms that modulate

cytokine production throughout the infection. Controlling the secretion of pro-inflammatory cytokines by macrophages are essential events needed to avoid the progression of dengue disease. A study has shown that human monocyte-derived macrophages differentiation in the presence of vitamin D restricts DENV infection by influencing DENV binding to cells (63). In addition, they showed that secretion of TNF- α , IL-1 β , and IL-10 was significantly lower in DENV-infected MDMs treated with vitamin D than in MDMs without vitamin D treatments (63). Studies have shown evidence that vitamin D can control cytokine responses by indirect regulation of NF- κ B activity or by direct modulation of the VDR-dependent gene (60,62,63).

3.5. Vitamin D and Hepatitis C Virus

One of the leading causes of liver-related mortality is an infection caused by the hepatitis C virus. HCV is a single-stranded, enveloped virus belonging to the *Flaviviridae* family. In many adults, the infection caused by the virus is asymptomatic. If the infection does not resolve on its own, the infection can become chronic and cause irreversible liver damage (64). Due to this dangerous nature of the virus and the poor outcome of the disease on the patient's life, researchers are now looking at improved ways to prevent and treat the infection.

As vitamin D is known to be an immunoregulator, studies have been done to correlate the levels of vitamin D with the occurrence of vitamin D infection. Patients with liver disease are commonly accompanied by Vitamin D deficiency; however, the mechanism behind this occurrence is yet to be understood (65). 25-OH vitamin D has multiple effects, acting as an innate antiviral agent and also exhibits an anti-fibrotic effect, simultaneously capable of producing more than one benefit. In addition, vitamin D is a powerful immune-modulator known to play a significant role in inflammatory responses as well as fibrosis caused by HCV infection (48,66,67).

Vitamin deficiency is commonly observed in patients with chronic hepatitis C infection. While it is known that HCV infection can reduce the level of vitamin D in patients, it has been speculated that vitamin D levels before acquiring the disease and during infection can affect the disease outcome. One study conducted on immuno-competent patients with recurrent hepatitis c infection showed that the administration of vitamin D with antiviral therapy increased the likelihood of sustained viral response (SVR) (68). This finding has been backed up by other studies as well. One study found that supplementation of vitamin D with Peg- α -2b/ribavirin therapy will improve the immune response against HCV genotype 1 (69). Another study found that adding vitamin D to conventional Peg/RBV therapy for patients with HCV genotype 2–3 significantly improves viral response (70). Along with decreased probability of SVR, low vitamin D levels have also been correlated with severe fibrosis. It has been observed that the interaction of vitamin D with vitamin D receptors in fibroblasts can protect the cells from oxidative damage, can affect proliferation, gene expression, and migration of fibroblasts as well as reduces the inflammatory activity of liver stellate cells (71). However, some studies suggest that vitamin D supplementation

does not produce any significant improvements in disease outcome. A study found that vitamin D supplementation given with antiviral therapy for patients affected by HCV genotype 1 did not show any difference in efficacy of the treatment or produce any beneficial effects in terms of fibrosis progression (48).

Vitamin D can also be used as a prognostic factor in cirrhosis in HCV affected patients. Cut-off levels of less 7.2 ng/mL, which is related to high mortality rates, lower than 7.1 and 6.6 ng/mL predict mortality in SBP (spontaneous bacterial peritonitis) and HE (hepatic encephalopathy) patients, respectively (72). HCV-related cirrhosis could probably lead to vitamin D deficiency included malabsorption to portal hypertension and hydrolyzation of 25-OH vitamin D (72). However, when using vitamin D levels as a prognostic tool, certain factors should be considered. People who live in the Middle-East tend to exhibit lower vitamin D levels than people from other geographical areas due to factors such as darker skin color, consumption of diet poor in vitamin D, and others (73). It is wise to consider the effects of race and other factors, such as sun exposure and vitamin D supplements intake. It has been established that racial differences affect the 25-OH vitamin D concentrations, parathyroid hormone (PTH), and calcium homeostasis. The racial study, however, shows some limitations such as individual sun exposure, ancestry profile, and possible bias of measured vitamin D due to the time of the year the samples are collected (65,74). It has been known that people are more exposed to light during the summer months compared to the winter season, so this could give out false results that is agreeable to its suspected to the season the samples were taken.

Most of the findings on this subject suggest that vitamin D supplementation with antiviral therapy can improve the outcomes of the disease and prevents recurrence of HCV infection.

3.6. Vitamin D and HIV

The effect of vitamin D on the development of HIV infection and its prevention is still not known and needs to be studied; however, some researches have demonstrated that vitamin D levels in HIV patients can be used as prognostic markers. A study performed on untreated African women showed that a low vitamin D level was associated with poor prognosis of the disease (75). Again, factors such as race, sunlight exposure, weather, genetics, and others should be considered when using vitamin D as a prognostic tool since these factors can affect the level of vitamin D within populations.

Some studies also suggest that vitamin supplementation with viral therapy can improve the outcome of the disease. One study suggests that vitamin D deficiency is associated with higher rates of mortality. This can be due to the role vitamin D plays in regulating the immune system. Vitamin D induces the expression of antimicrobial peptides such as cathelicidin and defensin $\beta 2$ and, when the levels of vitamin D fall below 20 ng/mL, the cathelicidin response is not initiated, leading to further impairment of immune system and subsequent increase in opportunistic infections (76). Another study showed evidence that vitamin D supplementation hindered the disease progression. As

discussed earlier, vitamin D is involved in regulating the CD4 function and sufficient levels of vitamin D prevent viral entry into the cells and cytopathogenic effects (77).

Vitamin D supplementation can also be used to improve bone mineral density (BMD) and strengthen the bones to prevent fracture prevention (78,79,80). It is more important to check and characterize the vitamin D status in HIV-infected children because the peak bone mass is not reached until the age of 25 (78). Although vitamin D is relevant in people suffering from osteoporosis in African American people, the race is definitely a factor among HIV-infected people (81). There are other factors associated with low vitamin D levels in HIV-infected people, and this includes high body mass index (BMI) and obesity (78).

In the studies discussed above, it can be inferred that vitamin D levels are indicative of the prognosis of HIV infection, and vitamin D supplementation can improve the outcome of the disease.

3.7. Vitamin D and SARS-CoV-2

As of late 2019, the globe is facing a new pandemic named Covid-19. This pandemic originated in the Wuhan district of China and has rapidly disseminated all across the world. The causative agent behind this disease is SARS-CoV-2. This virus belongs to a large family of viruses known as *Coronaviridae*. Based on phylogenetic and genomic links, the viruses in this family can be divided into four genera: alphacoronaviruses, betacoronaviruses, gammacoronaviruses, and deltacoronaviruses (82). Like SARS-CoV and MERS-CoV that have caused epidemics previously, SARS-CoV-2 is also a betacoronavirus and consists of a non-segmented, single-stranded, positive-sense RNA that closely matches its predecessor, SARS-CoV (83). According to the genetic analysis of the viral genome done on patients in China, there are two types of SARS-Cov-2 viruses: L-type and S-type. The L-type is more common and infectious than the S-type, which is the ancestral version of the genome (84). The genome of SARS-CoV-2 virus codes for four proteins: spike (S), envelope (E), membrane (M), and nucleocapsid (N) proteins, all of which are essential for viral infectivity (85). The S (spike) protein, is relatively the most crucial in infecting the host. This protein is present on the surface of the virus, and it interacts with the ACE2 receptor of the host cell. Upon interaction, the proteases such as transmembrane protease serine 2 (TMPRSS2) cleave off the C-terminal of ACE2, which mediate membrane fusion between the viral particle and the host cell membrane, allowing the virus to enter the cell and begin replication (86,87,88).

SARS-CoV-2 is associated with severe respiratory disease and multi-organ failure; however, compared to other zoonotic-origin coronaviruses that cause infections in humans, such as the SARS-CoV from 2003, it is less lethal. A majority of people infected by the virus do not show any symptoms and, out of those who do present symptoms, only a small percentage is severely affected. This variability in symptoms can be attributed to the difference in immune response among individuals. Based on clinical findings, when the virus enters the body, it undergoes a non-severe incubation stage.

During this stage, if the immune system of the host elicits a specific immune response, the virus can be eliminated before the disease progresses. This ability to eliminate the virus during the initial stage of the disease is determined by the immune status of the individual (age, health condition, HLA type, ABO blood group, and others). If the host cannot eliminate the virus at the initial stage, the virus will attack tissues with high ACE2 receptor expressions such as the lungs and the kidneys. This will activate inflammation mediated by the innate immune system, specifically by pro-inflammatory cytokines such as (IL)-1B and IL-18 released by macrophages and type 1 T helper (Th1) released by immune cells, that will cause further damage to the organs and lead to the severe stage of the disease (89,90).

As vitamin D plays a crucial role in regulating the immune system and is known to be protective against viral infections, it is suspected that vitamin D levels may correspond to the likelihood of SARS-CoV-2 infection and the outcome of Covid-19. The areas where there is a higher incidence of Covid-19 are located on higher latitudes and have low exposure to sunlight. This could correlate to lower levels of vitamin D, which could increase the susceptibility to Covid-19 (91). It has also been found that people who are categorized as highly susceptible to Covid-19 also exhibit vitamin D deficiency. Those afflicted by chronic diseases such as diabetes mellitus and cardiovascular diseases, obese and older population are considered a high-risk group to Covid-19 and, in most cases, are vitamin D deficient (92,93).

In the lungs, type II pneumocytes are the main target of SARS-CoV-2 and are involved in surfactant production in the alveoli (94). Upon infection, these cells are destroyed by the severe immune response, which reduces the surfactant production in the lungs and often leads to complications in patients affected by Covid-19. Studies have shown that metabolites of 1,25-dihydroxy vitamin D stimulate the production of surfactants in type II pneumocytes and can reduce the surface tension caused by surfactant depletion in Covid-19 patients (95). Most complications caused by Covid-19 occur due to the severe immune response that damages integral organs. It has been found that vitamin D prevents excessive release of pro-inflammatory cytokines and chemokines by modulating the activity of macrophages and thereby preventing tissue damage (96).

Currently, data that directly correlate the effect of vitamin D on the susceptibility and severity of Covid-19 are lacking, but since vitamin D has multiple effects on the immune system, it is likely to be involved in modulating the immune response against SARS-CoV-2.

4. Conclusions and Future Directions

Vitamin D has immuno-modulating properties that affect both innate and adaptive immunity. As vitamin D plays an integral role in regulating the immune system, researchers have been studying the role of vitamin D disease mechanisms. Our review compiles the recent findings on the work done on relating the levels of vitamin D with different viral infections outcomes. We found that only few viruses have been studied in relation to the effect vitamin D has on them. While most of the work has been done on chronic infections such

as HCV and HIV, there is some substantial research done on the influenza and other viruses. Until now, there has been no direct correlation made to vitamin D levels and Covid-19 outcome. Other viruses have not been studied in depth. However, as this paper shows that vitamin D affects the immune system in various ways, future studies are needed to understand the role of vitamin D in preventing infections caused by various viruses as well as how re-stabilizing the vitamin D levels in diseased patients can improve the outcome of the disease. Some of the works mentioned above have shown some promising results and if experimentation with other viruses shows similar results, vitamin D can be used as a readily available and inexpensive form of adjunct therapy. This will help improve the outcome of the disease and the quality of life of patients.

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DYNAMICS OF ANGIOTENSIN-CONVERTING ENZYME-2 EXPRESSION IN THE RETINA IN EXPERIMENTAL DIABETIC RETINOPATHY AND ITS MODIFICATION BY INSULIN**Usenko K.***Candidate of Medical Science, MD**ORCID: 0000-0001-9907-6109**Bogomolets National Medical University,**Kyiv, Shevchenko boulevard, 13, 01032**<https://doi.org/10.5281/zenodo.20186451>***Abstract**

Activation of the renin-angiotensin system (RAS) of the eye is one of the factors in the development of diabetic retinopathy (DR). The effects of RAS are counteracted by a recently discovered axis involving angiotensin-converting enzyme type 2 (ACE2) and its product angiotensin 1-7. DR was modeled in 35 male Wistar rats. For this purpose, they were administered a single dose of streptozotocin at a dose of 50 mg/kg (Sigma-Aldrich, Co, China). Experimental rats were divided into two groups: control and with the administration of insulin (Novo-Nordisk A/S, Bagsvaerd, Germany). A multiple increase in the content of ACE2 in the diabetic retina was established, first the accumulation of its free isoforms, and then binding to cellular proteins. Insulin administration reduced the content of ACE2 on the 21st day and after 2 months of treatment. The results obtained showed a possible role of increased ACE2 expression in the pathogenesis of DR and revealed its decrease during insulin treatment.

Keywords: diabetic retinopathy, angiotensin-converting enzyme 2, insulin.

Background. Diabetic retinopathy (DR) is one of the most common vascular complications of diabetes mellitus (DM), and today remains the main cause of vision loss in people of working age [1]. The renin-angiotensin system (RAS) plays an important role in the regulation of adaptive reactions of the cardiovascular system, water and electrolyte metabolism and tissue remodeling. Its main mediator is angiotensin II, which mediates the immediate physiological effects of vasoconstriction and blood pressure regulation, and is involved in the development of inflammation, endothelial dysfunction, atherosclerosis and arterial hypertension [2].

RAS is a causal factor in diabetic microvascular complications, which causes a variety of tissue reactions, including vasoconstriction, inflammation, oxidative stress, cell hypertrophy and proliferation, angiogenesis and fibrosis [3]. Both clinical and experimental models of DR and hypoxia-induced retinal angiogenesis suggest activation of the RAS. In the retina, angiotensin II induces vascular vasoconstriction, activates angiogenesis, and modulates the function of GABAergic mechanisms in amacrine cells and affects glia [4].

The discovery of angiotensin-converting enzyme 2 (ACE2) led to the establishment of a new RAS axis, which includes ACE2, its product angiotensin 1-7, and its receptor, Mas [5]. This vasoprotective axis counteracts the proliferative, fibrotic, proinflammatory, and hypertrophic effects of the classical ACE/angiotensin II/angiotensin II receptor type 1 axis. Imbalance of the vasoprotective and vasoconstrictor RAS axis in ocular tissue may lead to the development and progression of DR, and enhancement of the protective ACE2/angiotensin (1-7) axis may counteract the effects of angiotensin II [5].

Thus, the status of RAS and its regulator, ACE2, may be important in the development of DR through its influence on the processes of inflammation and damage to retinal vessels under conditions of hyperglycemia.

The aim of the work is to determine the content of

ACE2 in the retina during the development of experimental diabetic retinopathy and to establish the effect of insulin therapy.

Materials and methods. The work was guided by the norms and principles of the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes (Strasbourg, 1986), the Council of Europe Directive 86/609/EEC (1986), the Law of Ukraine No. 3447-IV "On the Protection of Animals from Cruelty to Animals", the general ethical principles of animal experiments adopted by the First National Congress of Ukraine on Bioethics (2001). The study involved 35 three-month-old male Wistar rats weighing 140-160 g. Experimental diabetes and DR were modeled by a single intraperitoneal injection of streptozotocin (50 mg/kg; Sigma-Aldrich, Co, China). 5 animals were used to obtain initial data (intact). Subsequently, every three days, the level of glycemia was monitored using a glucometer and disposable test strips (ACCU-Chek Instant, Roche, Mannheim, Germany) in blood taken from the tail vein on an empty stomach. 3 days after the injection, the blood glucose content of animals that were injected with streptozotocin was not less than 15 mmol/l. The animals were observed for 3 months.

After 7 days, animals with persistent hyperglycemia (n=30) were blindly randomly divided into 2 groups of 15 individuals. In the 1st group (control), hyperglycemia treatment was not performed. In the 2nd group, short-acting insulin (Actrapid HM Penfill, Novo Nordisk A/S, Bagsvaerd, Denmark) was administered intraperitoneally every other day to the animals at a dose of 30 U. Animals were removed from the experiment after 7, 21 days and 3 months in an amount of 5 individuals in each group by lethal injection of thiopental (75 mg/kg). Determination of ACE2 content in retinal tissue lysates was performed by immunoblotting. For morphological studies, eyes were immersed in 10% neutral formalin solution and embedded in paraffin. Serial histological sections 2–3 µm thick were made from

paraffin blocks on a rotary microtome NM 325 (Thermo Shandon, England). Statistica 10 software (StatSoft, Inc., USA) was used for statistical analysis. Descriptive statistics were performed by calculating means and their standard errors. Sample means were compared using analysis of variance (ANOVA), with a p value <0.05 considered significant.

Results and discussion. After streptozotocin administration, animals of all groups developed persistent hyperglycemia with maximum values of glucose content in the blood of animals of the control group after 3 months of observation (17.22 ± 1.35 mmol/l). In animals treated with insulin, the glucose content was significantly lower (11.04 ± 1.02 mmol/l; $p < 0.05$). Hyperglycemia, which developed in animals after streptozotocin administration, was accompanied by early morphological manifestations of DR. A decrease in cell density in the ganglionic layer, edema of the inner plexiform layer, and dilation of capillaries along the inner surface of the retina were determined. On the 21st day, these changes progressed, edema of all retinal layers with vascular dilation and microthrombosis in the outer plexiform layer, thinning of the nuclear layers of the retina, areas of ischemia, and the formation of microaneurysms along the inner surface of the retina were detected. Later, signs of retinal dyscomplexation with loss of the structure of the layers were detected, as well as specific signs of DR – numerous microaneurysms and vascular anomalies on the inner surface, in the outer layers – the formation of cell proliferates. After insulin treatment for 3 months, a significantly better condition of the retina was morphologically noted. The retinal layers retained their normal structure, no vascular or proliferative changes were detected.

Determination of the ACE2 level in rat retinal tissues by immunoblot analysis allowed visualization of several zones of specific protein binding. The lightest of them had a molecular weight of less than 110 kDa and corresponded to isoforms of the intact ACE2 protein [6]. Higher molecular weight polypeptide zones had a mass of 150–320 kDa and corresponded to forms of ACE2 that form stable complexes with cellular ligands. Accordingly, it could be assumed that the ACE2 110 kDa fraction reflected the level of the *de novo* synthesized enzyme, while the ACE2 > 110 kDa fraction was a functionally active form of this protein in the RAS tissue.

In intact animals, the content of ACE2 110 kDa in the retina was at the level of trace concentrations, while ACE2 > 110 kDa was not detected. With the development of DR, a 10.2-fold increase in the content of ACE2 110 kDa and a 3.9-fold increase in the high molecular weight fraction was shown already on the 7th day ($p < 0.05$ for both comparisons). After 21 days, the enzyme content remained high, but a greater increase was found for the high-molecular fraction (10.7 times compared to intact), for the ACE2 110 kDa fraction – 5.7 times ($p < 0.05$ for both comparisons). The results obtained indicated an increase in the content of ACE2 in DR, with the expression of the enzyme itself being activated to a greater extent at the beginning of its development, while later the content of its form bound to cellular proteins increased more significantly, which indicated the activation of this RAS chain.

The use of treatment showed a decrease in the content of both ACE2 fractions on the 21st day when insulin was used (3.6 times for ACE2 110 kDa and 4.9 times for ACE2 > 110 kDa). After 2 months of treatment, the content of ACE2 was lower than in the untreated control (1.7 times for ACE2 110 kDa and 1.5 times for ACE2 > 110 kDa; $p < 0.05$). After 3 months, the content of both ACE2 fractions compared to the corresponding control was reduced by the use of insulin (1.15 and 1.5 times, respectively; $p < 0.05$). The greater effect was observed for the high-molecular fraction, which indicated a decrease in the binding of the enzyme to cellular proteins and, accordingly, inhibition of RAS activity.

The obtained results demonstrated important aspects of the participation of ACE2 in the pathogenesis of DR and its regulation by the applied treatment. The increase in ACE2 levels, especially the high-molecular fraction, indicated the activation of RAS in the development of DR. In the early stages of the disease, there was a predominant increase in the expression of ACE2 itself, while in the later stages, an increase in the high-molecular-weight fraction indicated the binding of the enzyme to cellular proteins, which could be a marker of disease progression. Insulin treatment reduced the levels of both forms of ACE2, indicating its positive effect on the regulation of RAS and improving metabolic status.

Thus, the results of the studies indicated the possibility of using ACE2 as a marker for monitoring pathological changes and the effectiveness of DR treatment, and also confirmed the important role of insulin therapy in the correction of RAS disorders. The significant and long-term (within 3 months) increase in ACE2 content in the retina after DR modeling that we established can be considered a reflection of the general activation of local RAS. The introduction of insulin was accompanied by a decrease in hyperglycemia, which could also explain the decrease in retinal ACE2 content. It should be noted that this reaction had a maximum degree on the 21st day, while the effect of insulin decreased in the future. Perhaps there was an accumulation of metabolic damage to the retina and the activation of RAS was mediated by mechanisms other than hyperglycemia.

Of particular importance was the establishment of the fact of ACE2 accumulation in the retina in DR for the question of the possibility of infection with coronavirus (SARS-CoV-2). It is known to damage almost all systems and organs and is a powerful comorbid factor that worsens the course of chronic human diseases, including diabetes [7]. The results of the study of the coronavirus disease (COVID-19) pandemic have shown that patients with diabetes have more adverse clinical outcomes and a high risk of developing ocular complications [8]. Since there is no doubt about the role of ACE2 as an entry gate for SARS-CoV-2, the establishment of an increase in its expression in retinal tissue in DR may explain the adverse clinical outcomes and the high risk of worsening of the course of DR in COVID-19.

Conclusions. In experimental DR, an increase in ACE2 expression was found in the rat retina, confirming the involvement of this important RAS regulator in the pathogenesis of diabetic retinal damage. A multiple

increase in the content of ACE2 was noted, first the accumulation of its free isoforms, and then binding to cellular proteins. The introduction of insulin reduced the content of ACE2 in the retina. The results obtained showed a possible role of increased ACE2 expression in the pathogenesis of DR and revealed its decrease during insulin treatment, which corresponded to the inhibition of the development of morphological signs of DR.

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INTERSTITIAL LUNG DISEASES: A RETROSPECTIVE CASE SERIES ANALYSIS IN A SPECIALIZED CENTER

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Abstract

Background: Interstitial lung diseases (ILD) comprise a heterogeneous group of diffuse parenchymal lung lesions characterized by progressive fibrosis and respiratory failure. Their diagnosis and management in a multidisciplinary hospital are clinically challenging due to a broad etiological spectrum and frequent patient polymorbidity.

Objective: To conduct a retrospective analysis of a series of 10 clinical cases of ILD of various etiologies hospitalized in a specialized center, evaluating demographic, clinico-functional, and therapeutic characteristics.

Materials and Methods: A retrospective analysis of the medical records of 10 patients with verified ILD (ICD-10 codes: J84.8, J84.9, M34.8) was performed. Data analyzed included demographics, etiology, chest CT results, spirometry, oxygen saturation, and comorbidities. All data were fully de-identified.

Results: Of the 10 patients, 6 (60%) were men and 4 (40%) were women; the mean age was 54.6 ± 20.4 years (range 3–74 years). The identified etiologies were: ILD-COPD overlap (3 patients, 30%), RA-associated ILD (2 patients, 20%), idiopathic/unspecified ILD (2 patients, 20%), post-infectious ILD (2 patients, 20%), and SSC-associated ILD (1 patient, 10%). Among patients with available spirometry data ($n=5$), the mean FVC was $52.2 \pm 14.4\%$ and FEV_1 was $50.3 \pm 3.9\%$. Grade II–III respiratory failure was identified in 4 out of 10 patients (40%). Pulmonary hypertension was diagnosed in 3 patients (30%). The most common comorbid conditions were: AH (60%), HF (50%), COPD (30%), CAD (30%), and PH (30%).

Conclusion: The case series analysis demonstrates marked clinical heterogeneity of ILD, a high frequency of cardiovascular comorbidity and pulmonary hypertension, as well as the necessity for a multidisciplinary approach to managing this patient category. The findings align with current international ATS/ERS/JRS/ALAT recommendations.

Keywords: interstitial lung diseases, clinical case series, retrospective analysis, pulmonary fibrosis, respiratory failure, rheumatoid arthritis, systemic sclerosis, pulmonary hypertension, COPD, spirometry.

INTRODUCTION

Interstitial lung diseases (ILDs) constitute a broad and heterogeneous group of diffuse parenchymal lung diseases, comprising over 200 nosological forms with varying pathogenic mechanisms but shared clinical, radiological and functional manifestations [1, 2]. The common pathomorphological substrate is inflammation and/or fibrosis of the lung interstitium, which inevitably leads to progressive respiratory failure (RF) and a reduced quality of life for patients [3].

According to the 2013 ATS/ERS/JRS/ALAT international classification, ILDs are subdivided into idiopathic interstitial pneumonias (IIPs), ILDs associated with systemic connective tissue diseases (SCTDs), hypersensitivity pneumonitis, occupational ILDs, and

other forms [4]. Among IIPs, idiopathic pulmonary fibrosis (IPF) occupies a special place, characterised by a UIP pattern on high-resolution CT and an extremely poor prognosis: the median survival is 2–5 years without specific antifibrotic therapy [5, 6].

IPF in rheumatoid arthritis (RA-IPF) is one of the most common extra-articular manifestations of RA, occurring in 10–30% of patients undergoing CT scans [7]. EI in systemic sclerosis (SS-EI) is characterised by a predominance of the NSIP pattern and occurs in 35–70% of patients with SS, being the leading cause of mortality in this condition [8, 9]. The ILD-COPD overlap syndrome presents particular diagnostic challenges,

as restrictive changes are masked by underlying obstruction, which significantly complicates the assessment of the severity of pulmonary impairment [10].

Pulmonary hypertension (PH), which develops as a complication of IPF, falls into WHO Group 3 and is associated with a markedly poor prognosis — the 5-year survival rate for IPF+PH does not exceed 25–30% [11]. A wide range of comorbid conditions — cardiovascular disease, diabetes mellitus, chronic kidney disease — significantly complicates the use of both anti-fibrotic drugs (nintedanib, pirfenidone) and immunosuppressive therapy [12, 13].

In Kazakhstan, as in other countries with economies in transition, epidemiological data on IBD are limited, and the organisation of specialised multidisciplinary care is still in its infancy [14]. Publications of case series are of significant value for the establishment of registries, the analysis of clinical practice, and the development of clinical guidelines at the national level [15].

The aim of this study is a retrospective analysis of a series of 10 clinical cases of IBD of various aetiologies, verified at a specialised centre (JSC 'NCKIV', Almaty), with an assessment of demographic characteristics, the aetiological spectrum, clinical and functional indicators, the frequency of comorbid conditions, and the therapeutic strategies employed.

MATERIALS AND METHODS

Study design. A retrospective descriptive case series study. Medical records were analysed for 10 patients hospitalised for IHD or with a confirmed diagnosis of IHD between 2024 and 2025 inclusive.

Inclusion criteria. The analysis included patients: (1) with a verified diagnosis of ILD according to ICD-10 codes (J84.8, J84.9, M34.8 with pulmonary involvement); (2) with available chest CT scan data or a clinically and radiologically confirmed diagnosis; (3) with available data on comorbidity, severity of chronic obstructive pulmonary disease (COPD) and treatment received.

Exclusion criteria. Patients with an unverified diagnosis, insufficient medical documentation, or suspected malignant lung tumours as the primary cause of changes on CT were excluded.

Data collection. The following data were extracted from medical records: gender, age, diagnosis (primary and comorbid), ICD-10 code, severity of respiratory failure (RF 0–III according to clinical and functional criteria), spirometry results (FEV_1 , Tiffeneau index), peripheral blood oxygen saturation (SpO_2), radiographic/CT characteristics, immunological test results (ANA, SCL-70, RF, CRP), as well as treatment regimens used. All patients' personal data have been fully de-identified in accordance with bioethical requirements: patients have been assigned serial numbers (Patient No. 1 – No. 10).

Aetiological classification. All cases of ILD were classified according to aetiological principles: (1) ILD associated with CSD (RA, SSc); (2) COPD-overlap; (3) post-infectious ILD (following COVID-19, tuberculosis, viral-bacterial pneumonia); (4) idiopathic/unspecified ILD; (5) ILD with possible occupational aetiology.

Functional assessment. The severity of hypoxemia was assessed based on clinical criteria and SpO_2 : Hypoxemia 0 — $SpO_2 \geq 95\%$, Hypoxemia I — $SpO_2 90–94\%$, Hypoxemia II — $SpO_2 75–89\%$, Hypoxemia III — $SpO_2 < 75\%$ or requirement for mechanical ventilation. Spirometry data were interpreted according to the 2022 ATS/ERS criteria. A restrictive pattern was defined as $FEV_1/FVC \geq 0.70$ and a $FVC < 80\%$ of predicted.

Pulmonary hypertension. PH was diagnosed when the pulmonary artery systolic pressure (PASP) was > 35 mmHg as determined by echocardiography, in accordance with the 2022 ESC/ERS criteria (type 3 — due to lung pathology).

Statistical analysis. Due to the small sample size ($n=10$), the statistical analysis is descriptive in nature. Quantitative variables are presented as the mean $\pm$ standard deviation ($M \pm SD$) or the median with interquartile range (Med [Q1; Q3]) in cases of non-normal distribution. Qualitative variables are presented as absolute values and percentages. The normality of the distribution was tested using the Shapiro-Wilk test.

RESULTS

The study included 10 patients. Of these, 6 (60%) were men and 4 (40%) were women. The mean age of the patients was 54.6 ± 20.4 years (range 3–74 years). Excluding the paediatric patient (Patient No. 1), the mean age of the adults was 58.9 ± 12.9 years, which corresponds to data from international IHD registries [16]. The majority of patients (70%) were in the 35–74 age range.

By aetiological classification, patients were distributed as follows: ILD-COPD overlap (Patients No. 5, 7, 8) — 3 cases (30%); IPF associated with RA (Patients 2, 3) — 2 cases (20%); idiopathic/unspecified IPF (Patients 4, 6) — 2 cases (20%); post-infectious ILD (Patients No. 1, 10, with signs of a UIP pattern in the latter) — 2 cases (20%); ILD in SLE (Patient No. 9) — 1 case (10%). In Patient No. 10, immunological screening (SCL-70, ANA, ANCA, dsDNA) was negative, which, in the presence of a UIP pattern on CT, meets the criteria for idiopathic pulmonary fibrosis (IPF) according to the 2022 ATS/ERS/JRS/ALAT guidelines [5].

Stage 0 pulmonary fibrosis was recorded in 2 patients (20%); Stage I pulmonary fibrosis — in 3 patients (30%); Stage I–II pulmonary fibrosis — in 1 patient (10%); Stage II pulmonary fibrosis — in 3 patients (30%); Grade III DN was recorded in 1 patient (10%). Thus, severe DN (Grades II–III) was identified in 4 out of 10 patients (40%), indicating late diagnosis and/or high severity of the pathological process in this sample.

Spirometry results are available for 5 patients (50%). Among them: the mean FEV_1 was $52.2 \pm 14.4\%$ (range 38–74%), mean FEV_1 was $50.3 \pm 3.9\%$ (range 46–56%), and the mean Tiffeneau index (FEV_1/FEV_{10}) was $97.0 \pm 27.8\%$ (range 72–135%). A restrictive pattern ($FEV_1/FEV_{10}/FVC \geq 0.70$ with reduced FVC) was identified in 3 out of 5 patients. An obstructive component ($FEV_1/FVC < 0.70$) was recorded in 2 out of 5 patients (Patients No. 2 and No. 8), which corresponds to a mixed pattern of pulmonary functional impairment. Severe restriction ($FEV_1 38\%$) in Patient No. 10 is an unfavourable prognostic marker in ILF [6].

PH (WHO class 3) was diagnosed in 3 patients (30%): chronic cor pulmonale with class III PH in Patient No. 6; class III PH in Patient No. 10 (PA pressure 40 mmHg on echocardiography); PH as a complication of ILD in Patient No. 9. The presence of PH is associated with a significant deterioration in functional status and prognosis [11, 17].

Among the verified CT patterns: UIP pattern ('honeycomb lung', traction bronchiectasis) — 1 case (Patient No. 10); bilateral interstitial changes with fibrosis — 3 cases (Patients No. 6, 7, 9); polysegmental interstitial pneumonia — 2 cases (Patients 1, 4); linear pneumofibrosis — 1 case (Patient 2); bronchiectasis with fibrosis — 1 case (Patient 8). CT data were unclear or unavailable for 2 patients.

All 10 patients had ≥ 1 significant comorbidity. The mean number of comorbid conditions per patient was 3.8 ± 1.7 . The most common were: hypertension

— 6 (60%), heart failure — 5 (50%), COPD — 3 (30%), CHD — 3 (30%), pulmonary hypertension — 3 (30%), autoimmune thyroiditis/hypothyroidism — 2 (20%), RA — 2 (20%). A detailed breakdown of comorbidities is presented in Table 3.

Various therapeutic strategies were employed depending on the aetiology of IBD. Immunosuppressive therapy (methotrexate, leflunomide, mycophenolate mofetil, glucocorticoids) was used in 5 patients with SIBD or a post-infectious component. Antifibrotic therapy (pirfenidone, nintedanib) was considered in 2 cases (Patients No. 7, 10), but was limited by severe comorbidities. Bronchodilators (DHA, DBA, combined IGC/DBA) were used in 3 patients with IZL-COPD overlap. Long-term oxygen therapy was prescribed for Patient No. 10 (DN II, reduced SpO₂). Patient No. 1 (paediatric case) received immunotherapy and systemic GCS.

Table 1.

Demographic and clinical characteristics of patients

No.	Sex	Age (years)	ILD type / etiology	Main comorbidities	RF	SpO ₂ (%)	FVC (%)	Main therapy
1	F	3	Bilateral interstitial (viral-bacterial) polysegmental pneumonia; MIS-C	Iron deficiency anemia, DIC, CMV+EBV infection, GERD stage III, secondary immunodeficiency, CIPD	III	88	n/a	Dexamethasone, immunotherapy (Bioven), antibiotics
2	F	61	RA-associated ILD (J84.8)	RA (since 2023), COPD (since 2013), 40-year smoking history	0	n/a	51	Methotrexate 12.5 mg SC once weekly
3	F	59	RA-associated ILD (J84.8)	RA (since 2015–2016), hypertension (up to 180 mmHg), AIT, COVID-19 (2021, CT-3, 80% involvement)	0	97	Restrictive type	Leflunomide 20 mg/day, Methylprednisolone 4 mg/day
4	F	47	Unspecified ILD (J84.9); bilateral polysegmental interstitial pneumonia	Occupational chlorine exposure (36 years), pulmonary emphysema	I	n/a	48	Symbicort 160/4.5 µg, Berodual as needed
5	M	62	ILD (J84.8) + COPD group E, exacerbation	CAD, stable angina class II, post-stenting (RCA), HFpEF 58%, hypertension stage 2, chronic hepatitis C, asthma, type 1 diabetes, CKD stage 3b	I	n/a	n/a	Comprehensive therapy of comorbidities
6	M	65	ILD (J84.8); chronic cor pulmonale; pulmonary hypertension group III	CAD, post-infarction atherosclerosis (2021), PCI (RCA), CABG (LIMA-LAD, SVG-RCA), atrial fibrillation (tachysystolic), HFmrEF 50%, hypertension stage 2	II	n/a	n/a	Anticoagulants, cardiotropic therapy; evaluation of antifibrotic therapy

7	M	63	Fibrotic ILD (J84.8) + COPD group E; onset after ARVI (Feb 2020)	Hypertension stage 1 (risk 3), HFpEF 51%, weight loss 20 kg in 6 months	II	n/a	n/a	LAMA/LABA; systemic glucocorticoids; evaluation of nintedanib
8	M	35	Post-inflammatory residual changes; bilateral bronchiectasis (J84.8)	Pulmonary tuberculosis (2008–2011), chronic bronchitis since childhood; FVC 74%, FEV ₁ 46%	I–II	n/a	74	Antibiotics, bronchodilators, postural drainage
9	M	37	Progressive fibrosing ILD in systemic sclerosis (M34.8); ANA(+), SCL-70 (246)	Systemic sclerosis with skin, vascular (Raynaud's), GI (esophagopathy) involvement; RF 79, CRP 27	I	n/a	n/a	Mycophenolate mofetil 500 mg BID, Methylprednisolone 8 mg/day, Pentoxifylline, Nifedipine
10	M	74	Fibrotic ILD (J84.8); UIP pattern; honeycombing; traction bronchiectasis; PH class III	Hypertension stage 3, critical aortic stenosis (AVA 0.85 cm ²), MR grade 2, HFpEF 55% → 46%, CT-confirmed fibrosis	II	n/a	38	Oxygen therapy; pirfenidone under consideration; TAVI planned

Note: RF – respiratory failure; n/a – not available; AH – arterial hypertension; CHD – coronary heart disease; HF – heart failure; IDA – iron deficiency anaemia; DIC – disseminated intravascular coagulation; CIDP – chronic inflammatory demyelinating polyneuropathy; GERD – gastro-oesophageal reflux disease; COPD – chronic obstructive pulmonary disease; BA – bronchial asthma; AF – atrial fibrillation; RA – rheumatoid arthritis; AIT – autoimmune thyroiditis; SSc – systemic sclerosis; MPM – mycophenolate mofetil; GCS – glucocorticosteroids; ICS – inhaled GCS; LTAA/LTAB – long-acting anticholinergics/ β_2 -agonists.

Table 2.

Spirometric and functional parameters

Patient No.	Sex	Age (years)	FVC (%)	FEV ₁ (%)	FEV ₁ /FVC (%)	Ventilatory pattern	Respiratory failure grade
1	F	3	n/a	n/a	n/a	No data available (age-related limitation)	RF III
2	F	61	51	56	80	Restrictive (+ obstructive component)	RF 0
3	F	59	n/a	n/a	n/a	Restrictive pattern	RF 0
4	F	47	48	49	121	Restrictive	RF I
5	M	62	n/a	n/a	n/a	COPD + restriction (obstructive)	RF I
6	M	65	n/a	n/a	n/a	Restrictive + pulmonary hypertension	RF II
7	M	63	n/a	n/a	n/a	Restrictive + fibrosis	RF II
8	M	35	74	46	72	Obstructive (moderate)	RF I–II
9	M	37	n/a	n/a	n/a	Restrictive (SSc-ILD)	RF I
10	M	74	38	50	135	Severe restrictive (UIP pattern)	RF II
Total (n=5*)	—	Mean age 52,3	52,2 ± 14,4	50,3 ± 3,9	97,0 ± 27,8	*Patients with available spirometry data	—

Note: FVC – forced vital capacity; FEV₁ – forced expiratory volume in 1 second; Tiffeneau index; n/a – not available; respiratory failure; SSc – systemic sclerosis. *The mean value was calculated only for patients with available numerical spirometry data (n=5).

Table 3.

Prevalence of comorbid conditions in the study group (n=10)

Comorbid condition / disease	Number of patients (n=10)	Frequency (%)
Arterial hypertension	6	60
Heart failure (any class / EF)	5	50
Rheumatoid arthritis (RA)	2	20
COPD (diagnosed)	3	30
Bronchial asthma	1	10
Coronary artery disease (any form)	3	30
Systemic sclerosis (SSc)	1	10
Diabetes mellitus	1	10
Atrial fibrillation	1	10
Chronic kidney disease	1	10
Chronic viral hepatitis C	1	10
Autoimmune thyroiditis / hypothyroidism	2	20
Pulmonary hypertension (confirmed)	3	30
History of pulmonary tuberculosis	1	10
Severe COVID-19 with lung involvement	1	10
Occupational exposure (chlorine)	1	10
Iron-deficiency anemia	1	10
Cardiac valve disease (aortic stenosis / mitral insufficiency)	1	10

Note: AH – arterial hypertension; PH – pulmonary hypertension; MI – mitral insufficiency; AS – aortic stenosis.

DISCUSSION

This retrospective analysis of a series of 10 clinical cases of IHD enables us to characterise the actual clinical management of this patient group within a specialised multidisciplinary centre. The data obtained demonstrate marked heterogeneity in the nosological spectrum, severe comorbidity and a significant proportion of patients with moderate to severe renal impairment.

The demographic profile of the sample (mean age 54.6 years, 60% male) generally corresponds to the profile of hospitalised patients with acute myocardial infarction in specialised centres. According to data from international registries (EUROLD, INPULSIS), the mean age of patients with ILF is 65–70 years, whereas for ILD within the context of SCD it is 45–60 years [16, 18]. The presence of a paediatric patient (aged 3 years) with ILD in the context of severe viral-bacterial pneumonia and MIS-D highlights the uniqueness of the clinical setting. MIS-C (multisystem inflammatory syndrome in children) and associated interstitial lung changes represent a pressing nosological issue in the post-pandemic period, as highlighted in paediatric guidelines [19].

The most common aetiological group in this series was IBD-COPD overlap (30%), which corresponds to data from real-world clinical practice, where the combination of destructive and fibrotic changes is a common and prognostically unfavourable phenomenon [10, 20]. In patients with this pattern, FEV1 values may be pseudonormal due to the mutual offsetting of obstructive and restrictive components, which creates diagnostic difficulties and necessitates mandatory high-resolution CT to verify interstitial changes.

IPF in RA was recorded in 2 patients (20%). Both cases are characterised by a long history of RA and the use of basic anti-inflammatory therapy (methotrexate, leflunomide). It should be noted that methotrexate itself can cause drug-induced pneumonitis, which requires

careful differential diagnosis [7]. The presence in Patient No. 2 of both RA and COPD against a background of 40 years' smoking history clearly demonstrates the difficulties in attributing pulmonary involvement.

The sole case of SSc-ILD (Patient No. 9) presents a typical clinical picture: a young man with a long history of Raynaud's syndrome, positive ANA and high titres of SCL-70 anti-topoisomerase antibodies (246), progressive pulmonary fibrosis and a need for immunosuppression (mycophenolate mofetil, corticosteroids). SCL-70 positivity is the most significant predictor of ILD in SSc [8, 9]. The use of mycophenolate mofetil is consistent with the results of the SLS-I and SLS-II studies, which demonstrated its efficacy comparable to that of cyclophosphamide in SSc-ILD, with a better safety profile [21].

Patient No. 10 represents the most clinically severe case in the series: ILF with a UIP pattern on CT (honeycomb lung, traction bronchiectasis), severe restriction (FEV1 38%), pulmonary hypertension (PA pressure 40 mmHg) and critical aortic stenosis (AVA 0.85 cm²), making the use of antifibrotic therapy and surgical intervention associated with high risk. The co-existence of ILF and significant heart disease requires a multidisciplinary discussion involving a pulmonologist, cardiologist and cardiac surgeon [5, 22]. Discussion of the possibility of TAVI (transcatheter aortic valve implantation) in this patient is warranted in light of the high surgical risk associated with open surgery.

The high prevalence of cardiovascular comorbidities (hypertension 60%, heart failure 50%, coronary artery disease 30%, PH 30%) in the present series corresponds to data from large IHD registries and is explained by common pathogenetic mechanisms: systemic inflammation, oxidative stress and hypoxaemia [12, 17]. Progressive hypoxaemia in severe IHD is the leading mechanism in the development of stage II–III PH and right ventricular failure. The prevalence of PH identified in our series (30%) slightly exceeds the

data from epidemiological studies (15–25% in mild IHD) [11], which may reflect the selective nature of the sample from a specialist centre.

Functional parameters in the group of patients who underwent spirometry indicate a significant reduction in FEV₁ (mean 52.2%), which, in combination with CT lung function data, corresponds to moderate and severe restriction. It should be emphasised that a normal or only slightly reduced FEV₁ value does not rule out severe IPF with concomitant emphysema (IPF-COPD overlap) [10]. The sole obstructive pattern with minimally altered FEV₁/FVC ratio and normal FEV₁ (Patient No. 2) indirectly confirms this phenomenon.

The therapeutic approaches in the study group reflect the current consensus on the management of IBD. Immunosuppressive therapy (methotrexate, leflunomide, MMF, GCS) is indicated for SIBD and a number of forms of post-infectious IBD. Antifibrotic agents (nintedanib, pirfenidone) are first-line therapy for ILD and progressive fibrotic ILD [5, 23]. Nintedanib is also approved for SSc-ILD (SENSCIS study) and for ILD-COPD with a progressive phenotype [24]. The use of these drugs in clinical practice is limited by their high cost, severe comorbidity and the need for liver function monitoring.

Study limitations. The main limitations of this analysis are: (1) a small sample size (n=10), which does not allow for statistically significant comparisons; (2) a retrospective design with incomplete data (no spirometry in 50% of patients); (3) the absence of data on histological verification of the diagnosis for the majority of patients; (4) heterogeneity of observations in terms of diagnosis, age and severity. Nevertheless, a series of clinical cases is a valuable tool for the initial characterisation of the patient population and for generating hypotheses for subsequent prospective studies [15].

CONCLUSION

A retrospective analysis of a series of 10 clinical cases of ILD at a specialist multidisciplinary centre allows the following conclusions to be drawn.

1. The aetiological spectrum of ILD in the study group is characterised by marked heterogeneity: the most common subgroups were ILD-COPD overlap (30%), SSc-associated ILD (RA + SSc, 30%) and idiopathic/unspecified ILD (20%).

2. Severe respiratory failure (grade II–III) was identified in 40% of patients, indicating late presentation and/or high disease severity in this sample.

3. Functional parameters (FVC 38–74%, FEV₁ 46–56% in those examined) indicate moderate to severe impairment of lung function, consistent with the clinical picture.

4. The high prevalence of cardiovascular comorbidities (hypertension — 60%, heart failure — 50%, coronary artery disease — 30%) and pulmonary hypertension (30%) complicates therapeutic decisions and requires a multidisciplinary approach.

5. Modern therapeutic strategies (anti-fibrotic therapy for ILD, immunosuppression for SLE-associated ILD) were applied in accordance with international guidelines, but were limited by significant comorbidity in a number of cases.

The data obtained justify the need to establish a regional IHL registry in Kazakhstan, to standardise the

diagnostic algorithm with mandatory CT-lung and multidisciplinary discussion, and to increase the availability of antifibrotic drugs for patients with progressive fibrotic IHL.

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PEDAGOGICAL SCIENCES

THE ROLE AND IMPORTANCE OF SELF-EDUCATION IN THE FORMATION OF PERSONALITY

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Abstract

The process of personality formation occurs as a result of the complex interaction of biological heredity, social environment and purposeful upbringing. However, one of the most important conclusions of the sciences of pedagogy and psychology is that all these external factors become effective only through the internal activity and self-education of the individual. Self-education is a level of personality development in which a person consciously strives to improve himself, eliminate shortcomings in his character and acquire useful qualities for society. The role of this process in the formation of personality is manifested, first of all, in the strengthening of will and character. Through self-education, a person puts his inner world in order, learns to overcome laziness, lack of will and negative emotions. This turns the individual from a being who simply responds to external influences into an active subject who builds his own destiny and character. The importance of self-education for the personality is also associated with the deepening of the process of self-awareness. As the personality begins to work on itself, it begins to see its capabilities, abilities and spiritual potential more clearly. This system, called "Self-Concept" in psychology, is the sum of the ideas that the personality forms about itself. If an individual engages in self-education, these ideas about himself become more real and objective. This objectivity allows a person to set the right goals in life and mobilize internal resources to achieve these goals.

Keywords: system, personality, person, external influences, the right goals

In the absence of self-education, the formation of personality is spontaneous, and a person remains defenseless against the random influences of the environment. The role of self-education is indispensable in terms of ensuring moral and ethical maturity. In the process of education, certain ethical norms and rules of behavior are instilled in children and young people. However, these norms become an integral part of the personality only when the individual filters them through self-education and turns them into his inner convictions. For example, when qualities such as honesty or patriotism are perceived as an internal need, not under external pressure or fear, the personality is considered to have reached spiritual maturity. Self-discipline replaces external discipline with a sense of internal responsibility. This ensures that the individual takes a worthy place both in the collective and in society, and accelerates the process of social adaptation.

The dynamic requirements of the modern era have further increased the importance of self-discipline in the formation of personality. In the information society, it is inevitable for the individual to constantly renew himself, acquire new knowledge and skills. A personality with self-discipline habits does not lose heart when faced with any difficulty, but on the contrary, continues to develop by working on his mistakes. As noted by prominent educators, the main success of education is to create a need for self-education in the student. The freedom and self-realization of the personality begin from this point. A person who can control himself and act with his inner will is able to do more useful and creative things for himself and his state. Thus, self-education is both the engine of personality formation and the highest moral result.

In the process of personality maturation, self-education also serves as a filter. Thus, as a person develops, he does not perceive every information or educational influence coming from the environment as it is; he compares these influences with his internal value system. At this point, self-education acts as the most powerful shield protecting the individual from "mass psychology". An individual who educates himself prefers to remain true to his principles rather than fall under the influence of others, which is an indicator of the internal independence (autonomy) of the personality. Pedagogical studies show that students with self-education habits make calmer decisions in difficult life situations and are more resistant to stress. Because they set themselves the task of controlling their emotions and maintaining internal balance.

In addition, the importance of self-education is also clearly visible in the manifestation of the creative potential of the personality. As a person works on himself, he discovers his hidden abilities and shows the will to develop them. The famous teacher P.F. Kapterev noted that "true education and upbringing are self-education and self-discipline". This means that if any knowledge or qualities given from the outside are not combined with the internal efforts of the individual, they remain just an artificial shell. Self-discipline, on the other hand, breaks through that shell and penetrates the essence of the personality. Thus, self-discipline in the formation of personality is not just an auxiliary tool, but the main driving force of development, the most conscious step taken by the individual towards his spiritual elevation. The correct organization of this process will lead to the formation of a self-confident, socially integrated and spiritually n ensures the growth of rich citizens.

The process of self-education is not a random act, but requires the systematic application of certain methods and tools. In pedagogical literature, self-education methods are understood as the ways in which an individual influences his consciousness, feelings and will. The choice of these methods depends on the age, individual characteristics and the goal set. The most important and fundamental method of self-education is self-analysis. Before a person starts working on himself, he must be able to analyze his actions as an outside observer. Through self-analysis, an individual examines the reasons for his actions during the day, determines at what moments he shows lack of willpower or what negative characteristics (for example, quick temper, laziness) hinder him. This method helps a person to have an objective idea of himself and to form a real self-assessment.

Another important method after self-analysis is the method of self-promise (self-contract). This is when a person makes a commitment to himself to solve a certain problem or acquire a positive habit. For example, a student makes a firm promise to himself to be more responsible in his studies or to manage his time effectively. However, making a promise to himself is not enough; in order to control the fulfillment of this promise, the method of self-control must come into play. Self-control is the process of comparing an individual's behavior with the "ideal plan" he has determined. If an individual deviates from the promise he made to himself, he experiences internal anxiety, which reorients him to the goal. This process is often completed with self-reporting. At the end of the day, week, or month, a person evaluates his performance by asking himself the question "To what extent did I fulfill the task I set for myself?" One of the most "tough" and will-requiring methods of self-discipline is the method of self-command (self-control). This is a sharp activation of a person's will against his negative tendencies or momentary weaknesses. The method of self-command plays a decisive role, especially in difficult and unpleasant, but necessary, tasks. Another method close to this method is self-pressure. Sometimes a person puts himself in a situation where it is impossible to retreat and he must definitely show willpower. These methods strengthen the belief in the personality that "I must be able to do it." At the same time, self-reward applied after successful steps or self-reproach accompanied by a feeling of internal regret in case of failure are also effective means of influence. Self-reward creates positive emotions in a person and arouses the desire to continue self-education activities. As for the means of self-education, this includes external auxiliary resources that an individual uses to influence himself. One of the most important means in modern times is self-education and reading. Reading the life paths of great personalities, turning to books on ethical and psychological topics creates a kind of "educational standard" for the individual. Another means is keeping diaries. Writing a diary helps a person to systematize his thoughts, look at events calmly, and monitor the dynamics of development. Also, sports and physical labor are considered powerful means of self-education, because they require discipline and physical will. Thus, the complex application of methods and

means removes self-education from a mass of random attempts and turns it into a system of planned and effective development of the personality.

Although self-education is an internal matter of the individual, this process does not form spontaneously or spontaneously. Especially in school-age children and adolescents, since the criteria for self-assessment are not yet fully formed, they are in great need of professional pedagogical guidance. The teacher is the architect and coordinator of the self-education process. His main task is not to see the student simply as an object of education, but to create in him the need and desire to educate himself. In modern pedagogy, this is carried out within the framework of "subject-subject" relations. The teacher's role in this process begins, first of all, with helping the student discover his potential. The student perceives his strengths and aspects that need to be developed more honestly through the teacher's objective opinion and stimulating approach.

One of the most important factors that stimulate self-discipline in the school environment is the teacher's personal example. The teacher creates a "standard" in the eyes of students as a person who is constantly learning, able to admit his shortcomings and working on himself. If the teacher demands compliance with discipline and is late for class, then it is impossible for the student to develop a sense of self-control. At the same time, the teacher should set such difficult but manageable tasks for the students that they must demonstrate willpower when performing these tasks. Each successful difficult task strengthens the student's belief that "I can control myself". Pedagogical management here also includes teaching the student self-discipline methods (self-analysis, daily retention, planning). The teacher should teach the student that failure is not a disaster, but a stage from which it is important to analyze and learn.

The school team is also a powerful tool for self-education. A healthy competitive environment, ethical norms within the team and public opinion force the individual to look at his own actions from the outside. Various associations and self-government bodies created by the school (for example, the school parliament) practically teach students to take responsibility and regulate their own activities. The teacher should play the role of a hidden leader in this process; instead of giving direct orders, he should put the student in situations where the student has to give orders himself. This approach is called "pedagogical stimulation" and encourages him to develop without violating the inner freedom of the personality.

In addition, the teacher and school psychologist should regularly monitor whether the student's self-esteem is adequate. Some students may be overly demanding of themselves (low self-esteem), while others may be overly confident (high self-esteem). Both cases reduce the effectiveness of self-education. The teacher helps the student to draw the correct trajectory of self-education by bringing his ideas about himself closer to reality. Thus, the guiding role of the teacher is to transform the student from a passive executor into an active builder of his own life. The school should create an environment where "self-improvement" is perceived as the highest value. In this case, the educational

institution becomes a center that not only imparts knowledge, but also cultivates a true personality. The teacher's guiding role in the process of self-education is also closely related to the upbringing of a sense of individual responsibility in students. The teacher should instill in the student that every success or failure is the result not only of external circumstances, but also of the individual's own efforts. For this purpose, "self-analysis hours" or discussions on spiritual topics organized under the guidance of the teacher in schools serve to enrich the inner world of students. School management and teaching staff should create a psychological climate where each student is not afraid of their mistakes, but rather views them as an opportunity for self-discipline. A student brought up in such an environment is able to maintain internal discipline without external pressure, which is the

highest peak of the school's mission of personality development.

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PEDAGOGICAL FOUNDATIONS OF USING ARTIFICIAL INTELLIGENCE TECHNOLOGIES IN THE PROCESS OF CHEMISTRY EDUCATION

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This article comprehensively examines the pedagogical foundations of using artificial intelligence (AI) technologies in the process of teaching chemistry. The study analyzes the methodological potential of adaptive learning systems, molecular visualization and modeling tools, virtual laboratories, and intelligent tutoring systems within the educational process. It is substantiated that AI technologies enable the adaptation of educational content by taking into account learners' individual knowledge levels, learning pace, and cognitive characteristics.

Аннотация

Бұл мақалада химияны оқыту процесінде жасанды интеллект (ЖИ) технологияларын қолданудың педагогикалық негіздері жан-жақты қарастырылды. Зерттеу барысында молекулалық визуализация және модельдеу құралдары, виртуалды зертханалар мен интеллектуалды оқыту жүйелердің білім беру үдерісіндегі әдістемелік мүмкіндіктері талданды. Жасанды интеллект технологиялары білім алушылардың жеке білім деңгейін, оқу қарқынын және танымдық ерекшеліктерін ескере отырып, оқу мазмұнын бейімдеуге мүмкіндік беретіні негізделді.

Keywords: Artificial intelligence, chemistry teaching methodology, virtual laboratory, molecular modeling, interactive simulations, intelligent tutoring systems, digital education, research skills.

Кілт сөздер: жасанды интеллект, химияны оқыту әдістемесі, виртуалды зертхана, молекулалық модельдеу, интерактивті симуляциялар, интеллектуалды оқыту жүйелері, цифрлық білім беру, зерттеушілік дағдылар.

XXI ғасырда ғылым мен технологияның қарқынды дамуы жаңа заманауи зерттеу әдістердің қалыптасуына алып келді. Соның ішінде жасанды интеллект (Artificial Intelligence, AI) көптеген ғылым салаларында маңызды құралға айналып отыр. Соңғы жылдары бұл технология химия ғылымының дамуына да елеулі әсерін тигізуде. Химиялық зерттеулердің күрделілігі мен деректер көлемінің артуы жаңа әдістерді қолдануды талап етеді. Жасанды интеллектің басты міндеттерінің бірі мамандандырылған жасанды интеллект жүйелерін адам мүмкіндіктеріне жақындатумен және олардың адам табиғатымен жүзеге асырылатын интеграциясымен байланысты мәселелерді шешу. Сондықтан, бұл міндет химия ғылымында да орындалып келеді. Жасанды интеллект химиялық процестерді модельдеу, реакцияларды болжау және жаңа материалдарды жобалау сияқты міндеттерді шешуде тиімді құрал болып табылады. Бұл технология химиялық деректерді талдауды жеделдетіп қана қоймай, сонымен қатар жаңа ғылыми гипотезаларды қалыптастыруға мүмкіндік береді. Соның нәтижесінде химиядағы зерттеу жұмыстарының тиімділігі артып, ғылыми жаңалықтарды ашу

процесі жылдамдауда. Соңғы жылдары білім беру жүйесінде маңызды өзгерістерге ықпал еткен жасанды интеллект технологияларын жаратылыстану ғылымдары мен химия білімінде, әсіресе өмір бойы білім алуды қолдайтын пәндік салаларда қолдануға деген қызығушылық айтарлықтай өсіп келеді [1, б.3].

Дегенмен, қазіргі қоғамдағы білім беру саласындағы туғызып жатқан проблемаларды шешуде кеңінен қолданылмайды. Америкалық педагог және философ Джон Дьюи оқытудағы негізгі мәселенің бірі теорияның өмірмен байланысының әлсіздігі екенін атап көрсеткен. Оның пікірінше: «Егер біз бүгін білім алушыларды кешегідей оқытатын болсақ, онда біз олардың ертеңін ұрлаймыз». Бұл пікір білім беру жүйесінде оқыту әдістерін жаңартудың қажеттілігін көрсетеді. Химияны оқытуда да тек дәстүрлі әдістермен шектелу білім алушылардың ғылыми ойлауын дамытуға жеткіліксіз екендігін сипаттайды.

Бұл мәселе ғылыми тұрғыда терең талданғанымен, практика жүзінде тиісті дәрежеде қарастырылмаған. Сондықтан, аталған мәселені шешу қазіргі уақытта өзекті болып отыр. Қазіргі

танда жасанды интеллект білім беру процесінде өзінің толық әлеуетін көрсете алмай отыр. Білім беру процесінде жасанды интеллектті пайдалану білім алушылардың когнитивті қызметін дамытуға және оқу материалдарының тиімділігін арттыру үшін және білім алушылардың ерекшеліктерін ескере отырып оқыту сапасын арттыруға мүмкіндік береді.

Тағы да бір айтатын мәселенің бірі химия ғылымы құбылыстар мен процестердің микродеңгейде жүзеге асуымен байланысты болғандықтан, абстрактілі ойлауды талап етеді. Абстрактілі ойлау – физикалық бақылау мүмкін емес нысандар мен процестерді елестету, олардың арасындағы байланысты түсіну және оларды теориялық тұрғыдан талдау мүмкіндігі. Химияны оқу барысында студенттер атомдық құрылым, химиялық байланыстар, молекулалық құрылым және реакция механизмдері сияқты күрделі ұғымдармен танысады. Дегенмен, көптеген студенттер бұл ұғымдарды тану және түсінуде қиындықтарға тап болады, себебі олар макроскопиялық деңгейде бақыланатын құбылыстар мен микроскопиялық деңгейде жүретін процестер арасындағы тікелей байланысты тани алмайды. Нәтижесінде білім алушылар химиялық заңдарды үйренуде, реакция механизмдерін түсінуде және химиялық құбылыстарды ғылыми тұрғыдан түсіндіруде қиналады. Бұл ғылымға деген қызығушылықтың төмендеуіне және оқу жетістіктерінің жеткіліксіздігіне әкелуі мүмкін. Сондықтан химияны оқытуда күрделі теориялық ұғымдарды түсіндірудің тиімді әдістерін қолдану өте маңызды [2, 6.75].

Осыған байланысты визуализация, модельдеу және сандық технологиялар химиялық құбылыстарды оқытуда маңызды рөл атқарады. Визуализация құралдары студенттерге көрінбейтін микроскопиялық процестерді елестету мүмкіндігін береді, ал модельдеу әдістері күрделі химиялық құрылымдар мен реакция механизмдерін жақсы түсінуге көмектеседі. Сонымен қатар, заманауи сандық технологиялар мен интерактивті құралдарды пайдалану студенттердің интеллектуалдық белсенділігін арттырады және оқу материалын тереңірек қабылдауға мүмкіндік береді.

Жоғарыда аталған мәселелерді шешу білім алушылардың оқу жетістіктерін жақсартып қана қоймай, мұғалімдердің жұмысына да оң әсер етеді. Қазіргі заманғы білім беру жүйелерінде дәстүрлі әдістерден басқа, білім беру процесінің тиімділігін арттыру үшін заманауи оқыту тәсілдері мен цифрлық технологияларға деген сұраныс артып келеді.

Зерттеулер көрсеткендей, білім алушылардың когнитивтік процестерін ғана емес, сонымен қатар олардың эмоционалдық жағдайы мен мотивациясын да ескеретін жасанды интеллект негізіндегі оқыту жүйелері білім алушылардың белсенділігі мен оқу нәтижелерін айтарлықтай жақсартады. Бұл тәсіл оқу мазмұнын тек оқушының интеллектуалдық ерекшеліктерін ғана

емес, сонымен қатар оның эмоционалдық жағдайын да ескере отырып, жеке қажеттіліктерге бейімдеуге мүмкіндік береді. Зерттеулер мұндай жүйе білім алушының оқу тапсырмаларына қатысуын арттыратынын және жалпы оқу тиімділігін жақсартатынын көрсеткен [3, 6.2].

Білім берудегі жасанды интеллект бойынша соңғы шолулар білім беру технологияларын жобалау мен енгізуде педагогикалық және әдіснамалық аспектілерге жеткілікті көңіл бөлінбегенін бірнеше рет атап өтті. Осыған байланысты білім берудегі жасанды интеллект технологияларын одан әрі дамытудағы ең маңызды қадамдардың бірі - мұғалімдер мен білім беру саласындағы зерттеушілердің технологиялық инновация процесіне белсенді қатысуы болып табылады.

Осы тұрғыдан алғанда, білім беру жүйесінде жасанды интеллект технологияларын тиімді енгізу тек техникалық шешімдермен шектелмеуі тиіс. Бұл үдеріс педагогикалық мақсаттармен, оқыту әдістемесімен және білім алушылардың танымдық ерекшеліктерімен тығыз байланыста жүзеге асырылуы қажет. Жасанды интеллект құралдары білім беру процесінде тек ақпараттық технология ретінде емес, оқу мазмұнын меңгеруді қолдайтын, білім алушылардың оқу әрекетін ұйымдастыруға ықпал ететін әдістемелік құрал ретінде қарастырылуы тиіс [4, 6.10].

Зерттеушілердің пікірінше, білім беру процесінде жасанды интеллект технологияларын қолдану оқу ортасын жаңғыртып қана қоймай, сонымен қатар білім алушылардың жеке оқу траекториясын қалыптастыруға мүмкіндік береді. Интеллектуалды оқыту жүйелері білім алушылардың білім деңгейін, оқу қарқынын және оқу қажеттіліктерін талдай отырып, оқу материалдарын бейімдеп ұсынуға қабілетті. Бұл өз кезегінде оқыту процесінің даралануына және білім алушылардың танымдық белсенділігінің артуына ықпал етеді.

Білім беру саласында жасанды интеллект технологияларын енгізудің тағы бір маңызды бағыты – күрделі ғылыми ұғымдарды визуализациялау және модельдеу мүмкіндігі. Әсіресе химия сияқты жаратылыстану ғылымдарында көптеген құбылыстар микродеңгейде жүзеге асатындықтан, оларды тікелей бақылау қиын. Мұндай жағдайда виртуалды зертханалар, интерактивті модельдер және симуляциялық бағдарламалар химиялық процестерді көрнекі түрде көрсетуге мүмкіндік береді. Бұл білім алушылардың теориялық білімді терең түсінуіне және ғылыми құбылыстарды жүйелі түрде қабылдауына жағдай жасайды.

Сонымен бірге жасанды интеллект технологияларын қолдану білім алушылардың зерттеушілік дағдыларын дамытуға да ықпал етеді. Интерактивті оқу ортасында білім алушылар гипотеза құру, тәжірибе нәтижелерін болжау және алынған деректерді талдау сияқты ғылыми-зерттеу әрекеттерін орындауға мүмкіндік алады. Мұндай оқу әрекеттері студенттердің аналитикалық

ойлауын дамытуға және ғылыми таным мәдениетін қалыптастыруға жағдай жасайды [5, 6.2].

Жүргізілген талдау химияны оқыту процесінде жасанды интеллект технологияларын қолдану білім беру жүйесін жаңғыртудың маңызды тетіктерінің бірі екенін айқындады. Жасанды интеллект құралдары оқу процесін тек цифрландырумен шектелмей, оны сапалық жаңа деңгейге көтеруге мүмкіндік береді.

Мектеп оқушыларына арналған оқу материалдарын жас ерекшелік тұрғысынан талдау негізінде, әрбір білім деңгейіне сәйкес келетін жасанды интеллект құралдарын іріктеп, ұсыныс ретінде жазылды.

Тақырып: Химиялық элементтердің периодтық жүйесі. Атом, молекула

Кесте

1 7-сыныпта PhET платформасын қолданудың әдістемелік моделі

Көрсеткіш	Мазмұны
Платформа	PhET
Оқу мақсаты	Атом құрылымын түсіндіру және периодтық жүйедегі заңдылықтарды анықтау
Платформаны таңдау негіздемесі	Бұл платформа атомның құрылымын (электрон, протон, нейтрон) динамикалық модель арқылы көрсетеді. Абстрактілі микродеңгей ұғымдарын визуализациялау мүмкіндігі 7-сынып оқушылары үшін аса маңызды
Сабақта қолдану тәсілі	Мұғалім «Build an Atom» симуляциясын қолдана отырып атом моделін көрсетеді; оқушылар электрон қабаттарын өздері орналастырып, атом тұрақтылығын зерттейді
Қалыптасатын дағдылар	Когнитивтік модельдеу, аналитикалық өңдеу және себеп-салдарлық қатынастарды анықтау қабілеттері

Аталған платформаны қолдану кесте 1-де көрсетілгендей 7-сынып оқушылары үшін күрделі микродеңгейдегі ұғымдарды меңгеруді жеңілдетеді. PhET симуляциялары визуалды модельдеу арқылы оқушылардың абстрактілі ойлауын нақты бейнемен байланыстырады. Нәтижесінде оқушылар тек теориялық білім алып қана қоймай, оны

тәжірибелік түрде модельдеу арқылы терең түсінеді. Бұл тәсіл функционалдық сауаттылықтың «түсіну және қолдану» компоненттерін тиімді дамытады.

Тақырып: Химиялық байланыс түрлері

Кесте 2

8-сыныпта LearningApps платформасын қолданудың дидактикалық негіздері

Көрсеткіш	Мазмұны
Платформа	LearningApps
Оқу мақсаты	Химиялық байланыс түрлерін (иондық, ковалентті, металдық) ажырату
Платформаны таңдау негіздемесі	Бұл платформа ұғымдарды жіктеу және салыстыруға арналған интерактивті тапсырмалар құруға мүмкіндік береді. Байланыс түрлерін ажырату – логикалық салыстыруды талап ететін тақырып
Сабақта қолдану тәсілі	Мұғалім «сәйкестендіру» және «жіктеу» тапсырмаларын құрастырады; оқушылар қосылыстарды байланыс түрлері бойынша бөледі
Қалыптасатын дағдылар	Жоғары деңгейлі ойлау дағдылары: классификациялау, логикалық пайымдау және аналитикалық талдау

Кесте 2-де берілген мәліметтерге сәйкес LearningApps платформасы химиялық байланыс түрлері сияқты салыстыруды қажет ететін тақырыптарда ерекше тиімді. Оқушылар әртүрлі байланыс типтерін интерактивті тапсырмалар

арқылы ажыратып, логикалық ойлау дағдыларын дамытады. Бұл әдіс білімді тек есте сақтаумен шектелмей, оны құрылымдау және қолдану деңгейіне жеткізеді.

Тақырып: Химиялық реакция жылдамдығы

Кесте 3

9-сыныпта OLabs виртуалды зертханасын қолдану әдістемесі

Көрсеткіш	Мазмұны
Платформа	OLabs
Оқу мақсаты	Реакция жылдамдығына әсер ететін факторларды анықтау
Платформаны таңдау негіздемесі	Реакция жылдамдығы – тәжірибелік бақылауды талап ететін тақырып. Бұл платформа виртуалды зертхана арқылы факторлардың әсерін модельдеуге мүмкіндік береді
Сабақта қолдану тәсілі	Оқушылар температура, концентрация өзгерісін тәжірибе арқылы бақылап, нәтижелерді салыстырады
Қалыптасатын дағдылар	Метатанымдық бақылау негізінде зерттеу жүргізу, талдау және қорытынды жасау қабілеттері

Кесте 3 мазмұнына сәйкес OLabs платформасы тәжірибеге негізделген тақырыптарды меңгеруде

жоғары тиімділік көрсетеді. Оқушылар реакция жылдамдығына әсер ететін факторларды өз

бетінше зерттеп, нәтижелерді талдайды. Бұл ғылыми зерттеу дағдыларын қалыптастырып, функционалдық сауаттылықтың «зерттеу және талдау» компоненттерін дамытады.

Тақырып: Стехиометрия

Кесте 4

10-сыныпта ChemCollective платформасын қолданудың практикалық-бағдарланған моделі

Көрсеткіш	Мазмұны
Платформа	ChemCollective
Оқу мақсаты	Реакция теңдеулері бойынша есеп шығару және зат мөлшерін анықтау
Платформаны таңдау негіздемесі	Стехиометрия теория мен есептеуді біріктіреді. Бұл платформа виртуалды тәжірибе мен есептеуді қатар жүргізуге мүмкіндік береді
Сабақта қолдану тәсілі	Оқушылар ерітінді концентрациясын есептеп, тәжірибеде тексереді
Қалыптасатын дағдылар	Сандық есептеу, білімді қолдану және аналитикалық өңдеу қабілеттері

Кесте 4-те ұсынылған дереуерді талдау нәтижесінде ChemCollective платформасы стехиометрия сияқты есептеуді талап ететін тақырыптарда ерекше тиімді. Оқушылар есеп нәти-

желерін виртуалды тәжірибе арқылы тексеріп, теориялық білімнің практикалық мәнін түсінеді. Бұл тәсіл білімнің қолданбалы сипатын арттырады.

Тақырып: Тірі организмдер химиясы

Кесте 5

11-сыныпта Sketchfab платформасын қолданудың кеңістіктік-когнитивтік моделі

Көрсеткіш	Мазмұны
Платформа	Sketchfab
Оқу мақсаты	Глюкоза молекуласының құрылымын түсіндіру
Платформаны таңдау негіздемесі	Органикалық қосылыстар кеңістіктік құрылымды талап етеді. 3D модель молекуланы толық түсінуге мүмкіндік береді
Сабақта қолдану тәсілі	Мұғалім глюкоза моделін көрсетеді; оқушылар молекуланы айналдырып, байланыстарды зерттейді
Қалыптасатын дағдылар	Кеңістіктік визуализация және аналитикалық талдау дағдылары

Кесте 5 мазмұнына жасалған талдау көрсеткендей Sketchfab платформасы органикалық химиядағы кеңістіктік құрылымды түсіндіруде маңызды рөл атқарады. Оқушылар молекулаларды үшөлшемді форматта зерттеу арқылы олардың құрылымын терең түсінеді. Бұл кеңістіктік ойлауды дамытып, күрделі ғылыми ұғымдарды меңгеруді жеңілдетеді.

Аталған құралдарды қолдану оқушылардың жеке оқу траекториясын қалыптастыруға, күрделі химиялық процестерді терең түсінуге және ғылыми зерттеу жұмыстарын орындауға жағдай жасайды. Нәтижесінде, жоғары деңгейдегі сыни және ғылыми ойлау дағдылары қалыптасады.

Сонымен қатар жасанды интеллект технологиялары білім алушылардың жеке ерекшеліктерін ескеретін оқыту ортасын қалыптастырып, оқу мазмұнын дараландыруға мүмкіндік береді. Бұл өз кезегінде білім алушылардың оқу мотивациясын арттырып, олардың зерттеушілік және аналитикалық дағдыларын дамытуға ықпал етеді. Алайда бұл мүмкіндіктердің толық жүзеге асырылуы жасанды интеллект құралдарын педагогикалық тұрғыдан негізделген әдістемемен ұштастыруға тікелей байланысты [6, б.5].

Осы тұрғыдан алғанда, химияны оқытуда жасанды интеллект мүмкіндіктерін тиімді пайдалану мұғалімнің кәсіби құзыреттілігіне, цифрлық сауаттылығына және инновациялық әдістерді меңгеруіне тәуелді. Сондықтан білім беру процесіне жасанды интеллект технологияларын

енгізу кешенді сипатта жүзеге асырылып, педагогикалық, әдістемелік және технологиялық аспектілердің өзара үйлесімділігі қамтамасыз етілуі тиіс.

Қорыта келе, химияны оқытуда жасанды интеллект мүмкіндіктерін тиімді әрі мақсатты түрде қолдану білім беру сапасын арттырудың, оқу процесін жетілдірудің және заманауи талаптарға сай бәсекеге қабілетті мамандар даярлаудың маңызды шарты болып табылады. Жасанды интеллект технологияларын ғылыми негізде және жүйелі түрде енгізу арқылы білім беру саласында елеулі нәтижелерге қол жеткізуге болады, бұл өз кезегінде білім сапасының тұрақты өсуіне негіз бола алады.

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PHARMACEUTICS

MELATONIN USAGE AMONG MEDICAL STUDENTS IN AL-IRAQIA UNIVERSITY: A SUBJECT REVIEW

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Abstract

1.1: Introduction: In response to challenges, many medical students turn to pharmacological sleep aids, including melatonin supplements, as means to regulate their sleep cycle.

1.2: Objectives: Assess the prevalence of melatonin use and its perceived benefits among in aliraqia university college of medicine.

1.3: Methodology: Data about demographics, time of melatonin use, perceived reasons for exogenous melatonin use, melatonin use in relation to exam periods, perceived safety, and adverse effects were gathered.

1.4: Results: About 100 students, 70% reported using exogenous melatonin for sleep disorders. Most participants reported using melatonin during and after exam periods. Additionally, several 37% believed that its use was safe. The predominant use patterns were daily and as needed, and this study observed a higher rate of use compared with previous studies in Al-Iraqia University College of Medicine. The most frequently reported adverse effect was headache 47%. A significant number of undergraduate male students in health specialties used melatonin. A high rate of melatonin use was noted during exam periods, which was attributed to sleep deprivation.

1.5: Conclusion: Additionally, a significant number of students from private universities reported using exogenous melatonin. Melatonin use is common among university students. Future research should use a reliable psychometric measure to test its effect on university students' sleep quality and quantity.

2. Introduction

Sleep is an essential biological function that plays a vital role in cognitive performance, memory consolidation, immune function, and emotional regulation. However, due to academic demands, stress, and irregular schedules, many university students—particularly medical students—experience chronic sleep deprivation and poor sleep quality. Studies have shown that medical students sleep significantly fewer hours than the general population, with many reporting difficulties in maintaining consistent sleep schedules due to long study sessions, clinical rotations, and night shifts. Sleep disturbances in this population have been linked to decreased academic performance, impaired clinical judgment, and an increased risk of anxiety, depression, and burnout ⁽¹⁾.

In response to these challenges, many medical students turn to pharmacological sleep aids, including melatonin supplements, as a means to regulate their sleep cycles. Melatonin, a hormone primarily secreted by the pineal gland, is integral to the regulation of the circadian rhythm, with levels rising in the evening to promote sleep onset and falling in the morning to facilitate wakefulness. Unlike prescription sedatives, melatonin is widely available over the counter and is often perceived as a safe and natural remedy for sleep disturbances. As a result, its use has increased significantly among students who experience difficulties in falling or staying asleep ⁽²⁾.

Although melatonin is generally considered safe, concerns remain regarding its long-term effects, potential for misuse, and the lack of standardized dosing guidelines. Many medical students self-prescribe melatonin without consulting a healthcare professional, assuming that its use is entirely risk-free. However, studies have shown that excessive or inappropriate use of melatonin can lead to adverse effects, including daytime drowsiness, dizziness, headaches, hormonal imbalances, and disruptions in natural melatonin production. Additionally, melatonin's effectiveness varies between individuals based on genetic factors, lifestyle habits, and sleep disorders, raising questions about its optimal use in this population ⁽³⁾.

Beyond its physiological effects, the increasing reliance on melatonin among medical students also raises ethical and professional concerns. As future healthcare providers, medical students' experiences with pharmacological sleep aids may influence their attitudes toward sleep management and prescribing practices. This trend highlights the need for greater awareness of evidence-based sleep hygiene practices and the potential risks associated with self-medicating for sleep disturbances ^(4,5).

Understanding the patterns, motivations, and consequences of melatonin use among medical students is essential for several reasons. First, it provides insight into whether students rely on melatonin as a temporary solution for acute sleep deprivation or if they are using it chronically without medical supervision. Second, it helps identify any misconceptions or knowledge gaps regarding melatonin's effectiveness, potential risks, and appropriate use. Third, it allows for the development of targeted educational interventions that promote healthier sleep habits, reducing the need for pharmacological sleep aids ^(6,7).

Finally, given that medical students are future healthcare professionals, their understanding and experiences with sleep management will shape their future patient care and recommendations.

This study aims to explore the prevalence, motivations, and effects of melatonin use among medical students. Specifically, it seeks to assess how frequently medical students use melatonin, their reasons for doing so, their knowledge of its potential risks, and any self-reported side effects. By analyzing these factors, this research aims to contribute to a broader understanding of sleep health in medical education and inform strategies to promote safe, evidence-based sleep management practices among students. With the increasing reliance on melatonin supplements, it is imperative to examine their role in medical students' sleep behaviors and overall well-being, ensuring responsible usage in this academically demanding population.

2. METHODOLOGY

The methodology section serves as the blueprint for executing the research objectives with precision, rigor, and reliability. In this section, we delineate the methodological framework guiding data collection, analysis, and interpretation, ensuring methodological transparency and integrity throughout the research process. A questionnaire was prepared and presented to the students of the Iraqi University in Baghdad (as a cross sectional study)on November 13, 2024, and it remained effective for one months,100 students from various colleges of the Iraqi University, especially the College of Medicine Research Design Central to this study is the adoption of a mixed-methods research design, synthesizing quantitative and qualitative approaches to capture the complexity and nuance inherent in the investigation of using melatonin and its multifaceted impacts. **Sampling Strategy:** - A purposive sampling strategy will be employed to recruit participants representative of the diverse demographic profile within the college community. Stratification by using melatonin to improved sleeping (strongly disagree, disagree, neutral, agree, strongly agree) will be utilized to ensure adequate representation across the spectrum, facilitating robust comparative analyses and insights generation. **Data Analysis** Quantitative data will be analyzed using statistical software packages, employing descriptive and inferential statistical techniques to elucidate patterns, associations, and correlations between variables of interest. Qualitative data will be subjected to thematic analysis, iteratively coding, and categorizing emergent themes to distil salient patterns and interpretations. **Ethical Considerations:** - Ethical principles

will underpin all facets of the research process, ensuring the protection of participants' rights, confidentiality, and anonymity. Informed consent will be obtained from all participants, and measures will be implemented to minimize potential harm or distress arising from participation.

Studying Type: - The methodological approach employed in this research encompasses a mixed- methods study design, leveraging a combination of cross-sectional survey methodology and Likert-scale survey instruments to comprehensively address the research objectives.

Questionnaire Structure: - Utilizing Google Forms, the questionnaire was disseminated electronically to participants, allowing for seamless access and submission of responses at their convenience. The online format facilitated efficient data collection and minimized logistical constraints associated with traditional paper-based surveys. The questionnaire utilized in this study was meticulously structured to encompass distinct sections, each tailored to capture diverse dimensions of the research inquiry. The questionnaire was divided into three main sections, each focusing on specific domains pertinent to the investigation of using melatonin and its multifaceted impacts. The number of questions was 17 multiple-choice and short answer: The first section (Anthropometric Information): the questionnaire gathered information on the sociodemographic characteristics of the students (Student grade, Gender). The second section: included 9 questions on patterns of exogenous melatonin use from the students' perspective, the main reasons for exogenous melatonin use, dose and the use of melatonin in relation to examination periods or after and time taking before sleeping, sleeping for (1-4 or 5-8) hours after taking, misused and taking another drug and what is it? The third section (Health-related Inquiries): Finally, perceived safety and improved sleeping or not, the list of potential adverse effects included headache, nausea, dizziness, sleepiness, or no side effects and feeling when used. The questions further investigated the recommend melatonin to other university students who have sleeping difficulties, rely melatonin to sleep (strongly disagree, disagree, neutral, agree, strongly agree)

3. Results:

- Total number of 100 medical students participated in the study. Among them, 47% were male and 53% were female.

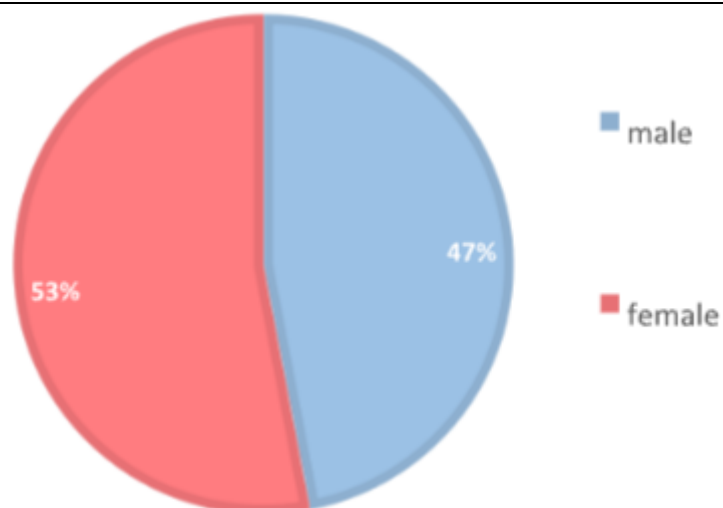


Figure 1: - Melatonin usage in both male and female.

70% of participants reported using melatonin as a sleep aid for insomnia

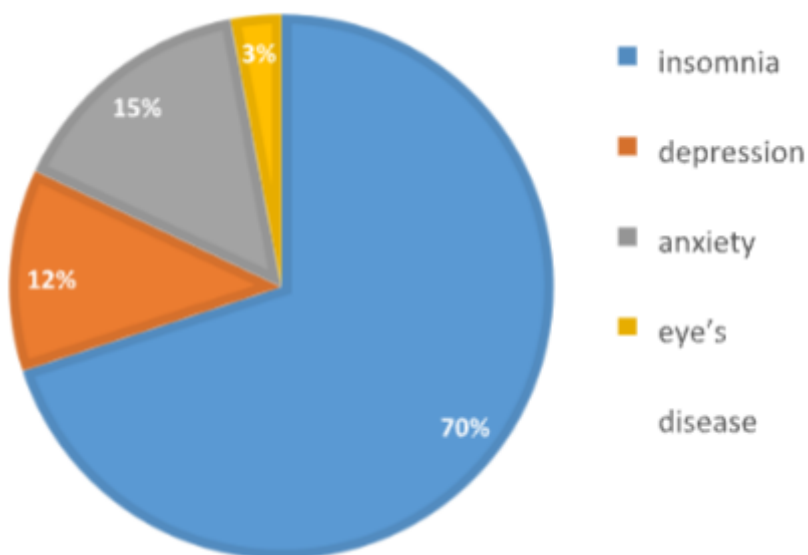


Figure 2: - Causes of melatonin use in participants.

The most commonly used dose was **10 mg**, with variations ranging from **1 mg** to **20 mg**.

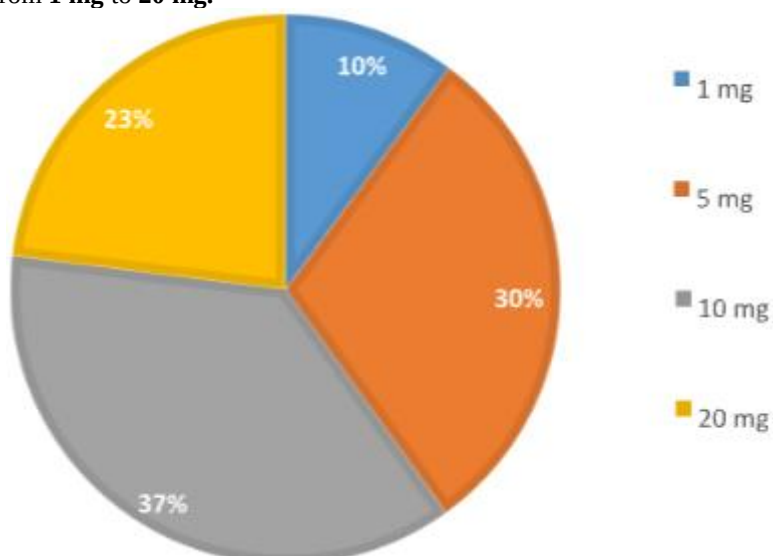


Figure 3:- The use of different dosage of melatonin.

Table 1

The time of melatonin taken before sleep.

Time before sleep	percentage
20-40 min.	48%
1 hr.	44%
2 hr.	8%

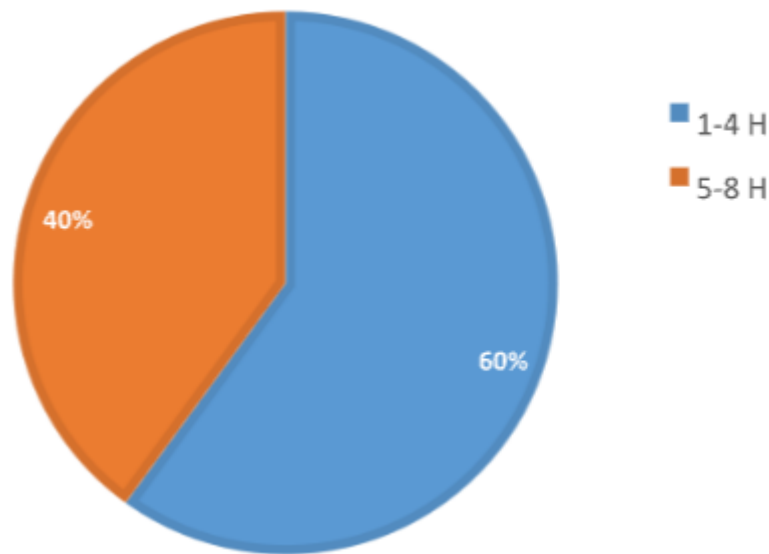
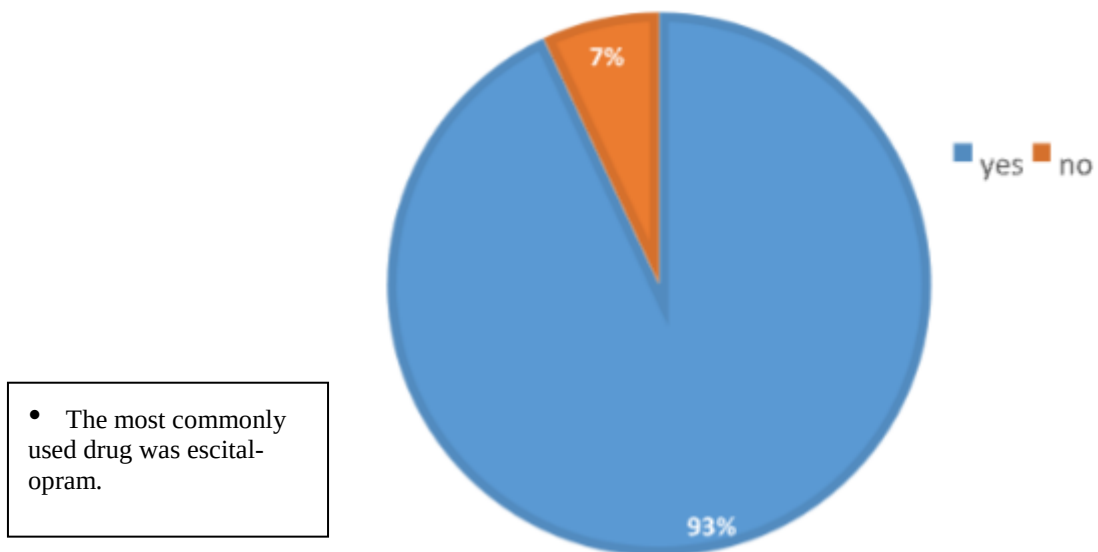


Figure 4: - Participants reported different sleep durations after melatonin use:

- 60% of users slept for 1-4 hours.
- 40% of users slept for 5-8 hours.



- The most commonly used drug was escitalopram.

Figure 5: - 93% of participants reported taking another drug alongside melatonin.
7% reported no use of additional medications.

Table 2

The most common side effects reported were:

Side effects	Percentage%
Headache	17%
Sleeping	16%
Dizziness	12%
Nausea	8%
No side effects	47%

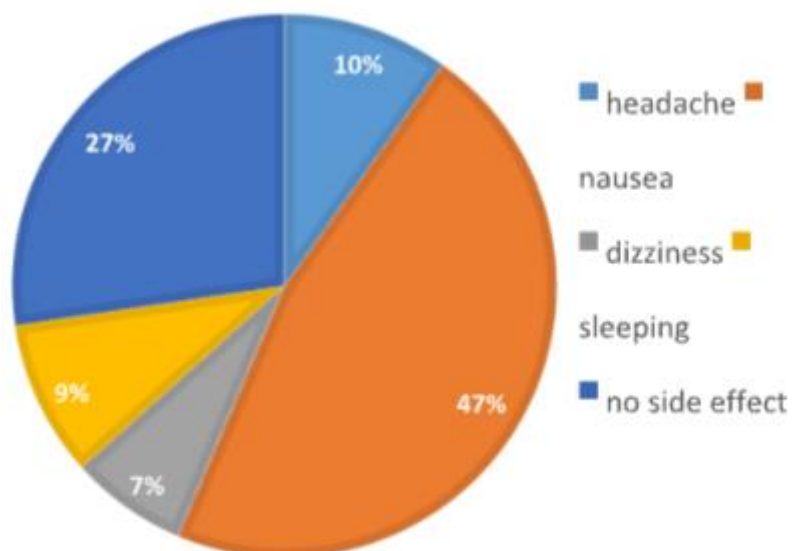


Figure 6:- Side effects that reported while using melatonin.

Table 3

How participants feel when taking melatonin.

Feeling of participants	Percentage%
Alertness	23%
Refreshed	10%
Dehydrated	6%
Irritated	5%
Dizziness	5%
Normal	51%

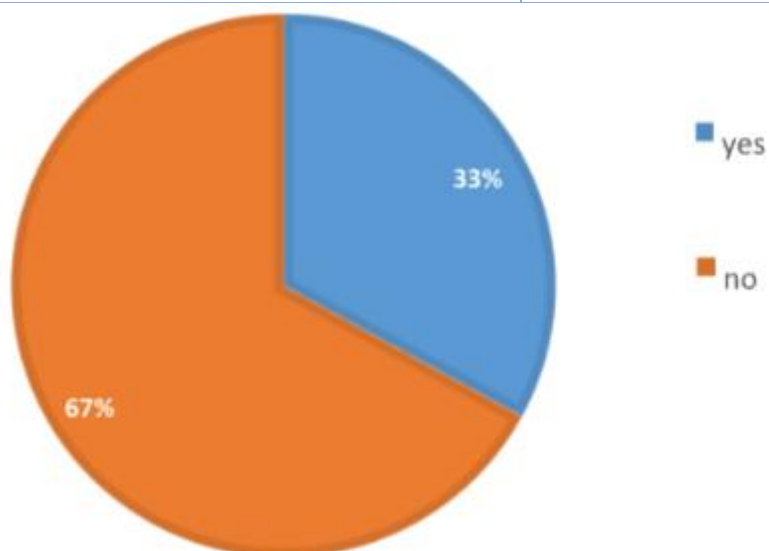


Figure 7: - 33% of students reported using melatonin during exams period.

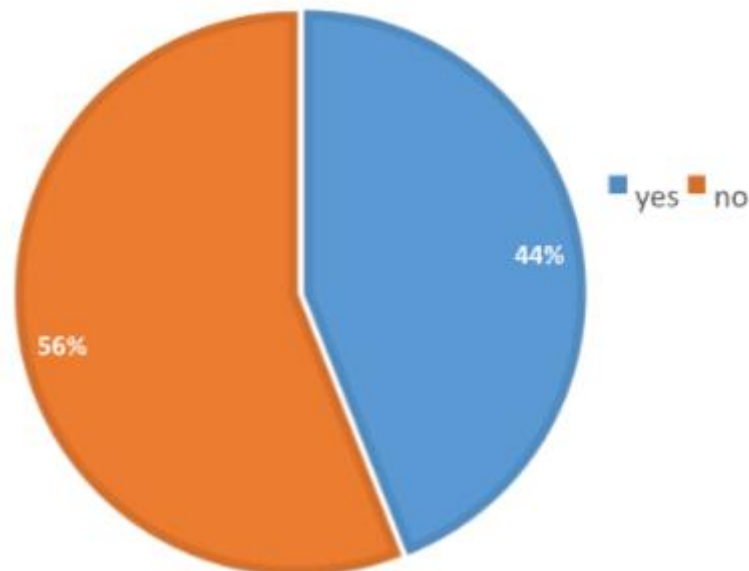


Figure 8:- 44% of students reported using melatonin after exams period.

Table 4 :- Feedback of participants about relying on melatonin to sleep.

Items	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
Melatonin has improved my sleep quality	8%	33%	46%	8%	5%
Melatonin is safe to use	17%	34%	30%	12%	7%
I will recommend melatonin to other university students who have sleeping difficulties	10%	40%	32%	7%	11%
I relay on melatonin to sleep	3%	17%	37%	25%	18%

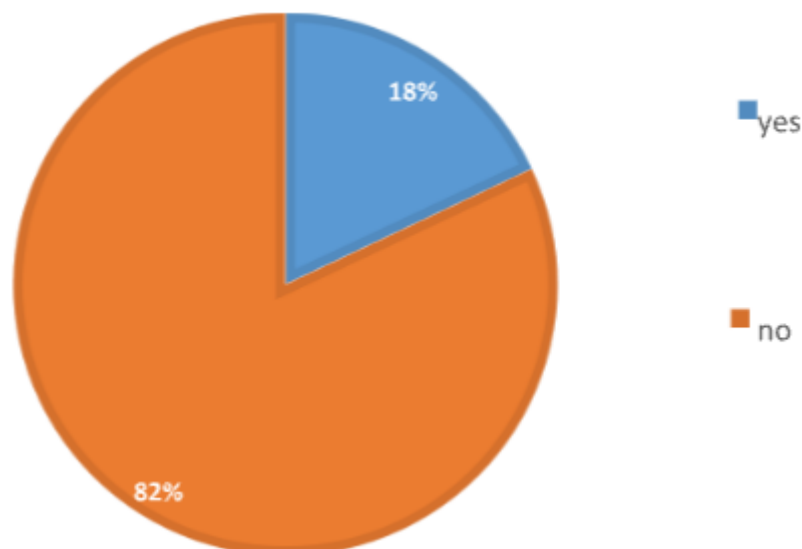


Figure 8: - 18% of participants have misused melatonin.

4. Discussion

This study assessed medical students' attitudes toward melatonin usage. The study also estimated the prevalence of melatonin misuse and the factors associated with it among al Iraqia medical students. These results provide valuable insights into the prevalence, patterns, and misuse of, and attitudes toward, exogenous

melatonin among university students. More than half of the participating students reported self-medication with melatonin to manage their sleep disorders. Similar studies have shown an increase in the self-prescription of melatonin among medical students to cope with the highly demanding learning environment and to meet

the expectation of managing the academic load. Medical students appear to consume a high quantity of sleeping aids, possibly owing to their greater familiarity with hypnotic agents by virtue of their studies. The observed higher rates of use could be attributed to misuse, perceived safety, observed low levels of adverse effects and easy access.

Another significant finding reported the high use of exogenous melatonin among students studying in health and/or medical schools compared with students studying in non-health related. The examination period showed relatively higher rates of use, which could be attributed to sleep deprivation.

This study also found that melatonin is perceived as safe and effective by university students. About 46% of these students reported as good effective concerning its effectiveness in improving the quality of sleep during examination periods. The study also show that female students are more likely to consume melatonin than the male.

The study provided evidence of factors associated with uses of melatonin, such as needing of more than 20 min to fall asleep, and sleeping almost for 5-8 hours. Notably, the results from this study concluded that 5 mg melatonin intake is effective in improving the psychomotor and physical performance of sleep deprived students.

Medical students' attitudes toward the usage of melatonin were assessed after considering the following as indicators of misuse: use of melatonin almost daily, use in greater amounts than the recommended dose and self-prescription, most students self-prescribed of melatonin, which was considered a misuse attitude. Similar studies have shown self-prescription to be a common issue among medical students; self-prescription is exacerbated by easy accessibility and the availability of several types of over-the-counter drugs, such as Panadol Night and melatonin. Although self-prescribed medications can have some benefits when used appropriately, it is a dangerous practice that can delay an accurate medical diagnosis and result in adverse effects, drug interactions, and developing dependence, thereby aggravating what was intended to be treated.

The rising prevalence of sleep disturbance and melatonin use among university students warrants further investigation and intervention strategies. Future research should explore the factors influencing melatonin use, including academic stress and, underlying mental health conditions, in depth⁽⁸⁻¹⁰⁾. Additionally, studies should assess the long-term effects of melatonin use in this population, particularly with regard to potential dependence on or interactions with other medications. Within universities and colleges, it is essential to offer students information, programs, and resources on sleep hygiene and the appropriate use of sleeping aids.

Notably, a multifaceted approach that combines education, mental health support, and accessible therapeutic interventions can help improve sleep health and reduce the reliance on melatonin among university students^(11,12).

Universities and health services can play a pivotal role in addressing this issue. Proactive measures include educational programs such as workshops and

seminars on healthy sleep habits, the risks and benefits of melatonin, and alternative sleep promoting strategies. These initiatives can empower students to make informed decisions about their sleep health. Increasing access to mental health services and promoting help-seeking behaviors can address the underlying conditions contributing to sleep disturbance and consequent melatonin use^(13,14).

Despite these limitations, this study sheds light on the prevalence of regular melatonin uses among university students in IUCOM; this may inform future research and lifestyle medicine interventions targeting university students.

Conflict of Interest

The authors declare that there is no conflict of interest.

Acknowledgement

Authors would like to thankful university of Al-Iraqia for offering a great support for current study.

5. Questionnaire:

5.1 Series 1: indication of Melatonin use:-

1. I use melatonin for:

- ☒ A) **Insomnia**
- ☐ B) Depression
- ☐ C) Anxiety
- ☐ D) Eye's disease

2. How much times are you taking Melatonin before sleep:

- ☒ A) **20-40 minutes**
- ☐ B) 1 hour
- ☐ C) 2 hours

3. How many hours do you sleep after taking Melatonin:

- ☒ A) **1-4 hours**
- ☐ B) 5-8 hours

4. Are you taking another drug while using Melatonin, what is it:

- ☒ A) **Yes**
- ☐ B) No

5. Commonly used dose of Melatonin:

- ☐ A) 1mg
- ☐ B) 5mg
- ☒ C) **10mg**
- ☐ D) 20mg

6. I use Melatonin during my exams:

- ☐ A) Yes
- ☒ B) **No**

7. I use Melatonin after my exams:

- ☐ A) Yes
- ☒ B) **No**

8. Have you ever misused Melatonin:

- ☐ A) Yes
- ☒ B) **No**

5.2: Series 2: Physical effect of Melatonin on the student:

1. Side effect appear while using Melatonin:

- ☐ A) Headache
- ☒ B) **Nausea**
- ☐ C) Dizziness

- D) Sleeping
- E) No side effects
- 2. How do you feel when taking Melatonin:
- A) Refreshed
- B) **Normal**
- C) Alert
- D) Dehydrated
- E) Irritated
- F) Dizzy

5.3: Series 3: Students opinion about using of Melatonin and its effect:

1. Melatonin has improved my sleep quality:

- A) Strongly agree
- B) Agree
- C) **Neutral**
- D) Disagree
- E) Strongly disagree

2. Melatonin is safe to use:

- A) Strongly agree
- B) **Agree**
- C) Neutral
- D) Disagree
- E) Strongly disagree

3. I will recommend Melatonin for other university students who have sleeping difficulties:

- A) Strongly agree
- B) **Agree**
- C) Neutral
- D) Disagree
- E) Strongly disagree

4. I rely on Melatonin to sleep:

- A) Strongly agree
- B) Agree
- C) **Neutral**
- D) Disagree
- E) Strongly disagree

6. Recommendation

Policy recommendations for the use of melatonin should focus on safety, efficacy, and public awareness. Here are some suggestions:

6.1: Public Education Campaigns

- Awareness Programs: Launch educational initiatives to inform the public about the appropriate use of melatonin, potential side effects, and the importance of consulting healthcare providers before starting supplementation. This could include information on when melatonin is beneficial versus when behavioral interventions may be more appropriate.

- Targeted Information for Specific Groups: Provide tailored guidance for vulnerable Regulation and Quality Control.

- Targeted Information for Specific Groups: Provide tailored guidance for vulnerable populations, such as children and the elderly, emphasizing that melatonin should not be used casually or without medical advice.

6.2: Research Funding

- Support Clinical Trials: Increase funding for research to explore the long-term effects of melatonin use, its efficacy across different sleep disorders, and its

interactions with other medications. This would help build a stronger evidence base for clinical recommendations.

- Investigate Broader Applications: Encourage studies into melatonin's potential benefits beyond sleep disorders, such as its role in managing mood disorders or metabolic conditions.

6.3: Healthcare Provider Training

- Continuing Education: Implement training programs for healthcare providers on the latest research regarding melatonin use, including its benefits, risks, and appropriate prescribing practices. This will enable providers to offer informed recommendations to patients considering melatonin supplementation.

By focusing on these areas, policymakers can help ensure that melatonin is used safely and effectively while maximizing its potential benefits for those struggling with sleep issues.

6.4: Communication and Consent

- Informed Consent: Patients or guardians must be informed about the off-label status of melatonin and the potential risks involved. Clear communication regarding treatment expectations is crucial.

- Collaboration with Primary Care: Ongoing communication with primary care providers is essential for monitoring treatment effects and making necessary adjustments.

These recommendations aim to optimize the use of melatonin while minimizing risks associated with its off-label use in various populations.

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PHILOLOGICAL SCIENCES

PRAGMATIC ADAPTATION WHEN TRANSLATING CARTOON/FILM TITLES

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ФИЛЬМ ЖӘНЕ МУЛЬТФИЛЬМ АТАУЛАРЫН АУДАРУДАҒЫ ПРАГМАТИКАЛЫҚ БЕЙІМДЕУ

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Abstract

This article examines pragmatic adaptation in translating film and animation titles through the IMRAD structure. A title is treated not only as a linguistic unit, but also as a tool of audience attraction, genre signalling, cultural transfer, and commercial impact. Drawing on studies from 2022–2025, the paper systematizes adaptation models, translation transformations, and their relevance to the Kazakh-language context. The practical section interprets well-known title translations to demonstrate their pragmatic load.

Аңдатпа

Мақалада фильм және мультфильм атауларын аударудағы прагматикалық бейімдеу мәселесі IMRAD үлгісінде қарастырылады. Атаудың тек тілдік бірлік емес, көрерменді тартатын, жанрды аңғартатын, мәдени кодты жеткізетін және коммерциялық ықпал жасайтын құрал екені талданады. Зерттеуде соңғы жылдардағы аудиовизуалды аудармаға арналған еңбектер негізінде фильм атауын бейімдеудің негізгі модельдері, трансформация түрлері және қазақ тілді кеңістікке қолдану тетіктері жүйеленеді. Практикалық бөлімде танымал фильмдер мен мультфильмдер атаулары нақты мысал ретінде алынып, олардың аудармадағы прагматикалық жүктемесі ашылады.

Keywords: translation, pragmatics, film title, animated title, adaptation, audiovisual translation, localization.

Кілт сөздер: аударма, прагматика, фильм атауы, мультфильм атауы, бейімдеу, аудиовизуалды аударма, локализация.

Кіріспе. Фильм мен мультфильм атауы көркем мәтіннің шеткі қабаты емес, қабылдаудың алғашқы сүзгісі болып саналады. Көрермен кино туындысының мазмұнымен, стилімен немесе идеясымен ең алдымен атау арқылы танысады. Сол себепті атау аудармасы сөзбе-сөз дәлдікке ғана емес, коммуникативтік әсерге, жанрлық бағдарға, мәдени танымға және нарықтық тартымдылыққа да тәуелді болады. Әсіресе қазақ тіліне аударуда бұл мәселе өткір көрінеді, өйткені бір атаудың астарында ағылшынтілді ойынсөз, мәдени ишара, ирония, мифологиялық символ, балалар аудиториясына бағытталған эмоционалдық жұмсарту немесе прокаттық стратегия қатар жатуы мүмкін. Зерттеудің

өзектілігі фильм және мультфильм атауларын аударуда формалық сәйкестік пен прагматикалық әсердің үнемі қабыса бермейтіндігінен туындайды. Зерттеудің мақсаты – фильм және мультфильм атауларын аударудағы прагматикалық бейімдеудің тілдік және функционалдық ерекшеліктерін айқындау. Міндеттері ретінде прагматикалық бейімдеудің теориялық негіздерін жинақтау, соңғы ғылыми еңбектерді салыстыра талдау, атау аудармасындағы негізгі стратегияларды анықтау және оларды қазақ тілді ортада қолданудың тиімді жолдарын ұсыну белгіленді. Зерттеу нысаны – аудиовизуалды аударма үдерісі, ал зерттеу пәні – фильм және мультфильм атауларын аударудағы

прагматикалық бейімдеу амалдары. Жұмыстың теориялық жаңалығы атауды тек лексикалық бірлік ретінде емес, көпқабатты коммуникативтік құрылым ретінде қарастыруында жатыр. Практикалық маңызы қазақ тіліне аударатын мамандарға, дубляж редакторларына, субтитр жасаушыларға және киноөнімді локализациялаушыларға нақты бағдар беруімен айқындалады.

Әдістер. Зерттеу сапалық сипаттағы салыстырмалы-талдамалық әдіске негізделді. 2022–2025 жылдары жарияланған фильм атауы, аудиовизуалды аударма, локализация, транскреация және прагматикалық бейімдеу жөніндегі еңбектер іріктеліп, олардың тұжырымдары жүйеленді. Сонымен қатар танымал фильмдер мен мультфильмдердің түпнұсқа және нысана тілдегі атаулары салыстырылып, олардың семантикалық сақталуы, жанрлық сигналы, эмоционалдық реңкі және коммерциялық тартымдылығы бағаланды. Қолданылған тәсілдер қатарында мазмұндық талдау, функционалдық интерпретация, прагматикалық модельдеу және мысалдық сараптау бар. Бұл бағыттағы зерттеулердің соңғы жылдары едәуір күшейгені аудиовизуалды аудармаға арналған библиометриялық шолулар мен теориялық шолуларда да көрсетіледі.

Нәтижелер. Соңғы зерттеулер фильм атауын аудару бір ғана тілдік ауыстыру емес, мәдени және нарықтық бейімдеу актісі екенін көрсетеді. Атауға қатысты жаңа шолуларда фильм атауы аудармасының зерттеу өрісі кеңейіп, онда прагматика, қабылдау, локализация, транскреация және платформалық таралым факторы қатар қарастырылып отырғаны байқалады [1, 1]. Сонымен бірге аудиовизуалды аударма саласының жалпы өсуі бұл мәселенің кездейсоқ емес, экран мәдениетінің жаһандануы нәтижесінде өзекті тақырыпқа айналғанын дәлелдейді [2, 112]. Фильм атауы енді сөздің мағынасы ғана емес, прокаттағы стратегия, жанрлық белгі және тұтынушылық қызығушылықтың тоғысқан тұсы ретінде бағаланады [3, 51].

Прагматикалық бейімдеудің негізгі принциптерінің бірі – атаудың көрерменге бірден түсінікті әрі тартымды болуы. Бұл мәселе фильм атауын мәдени феномен ретінде қарастырған еңбекте атау “өзге тіл мәдениеті өкілінің фильмді дұрыс қабылдауына жағдай жасайтын” трансформациялық нысан ретінде сипатталады [4, 152]. Тай аудиториясына арналған 501 фильм атауын талдаған зерттеуде жаңа атау беру, ішінара аудару, транслитерация мен қосымша түсіндіру сияқты амалдардың қатар қолданылуы аудитория күтімінің шешуші фактор екенін көрсетті [5, 195]. Вьетнам тіліне аудару тәжірибесін қарастырған жұмыста стратегия жанрға қарай өзгереді, яғни қорқынышты фильм, мелодрама және анимация атаулары бірдей модельмен берілмейтіні анықталған [6, 57].

Прагматикалық бейімдеу әсіресе романтикалық, комедиялық және балаларға арналған туындыларда айқынырақ көрінеді. 2020–2024 жылдардағы романтикалық фильм атауларын

талдаған зерттеуде локалды аудиторияға жақындатылған, мәдени жағынан ыңғайластырылған атаулардың жиі таңдалатыны көрсетілген [7, 89]. Қытай тіліне аударылған фильм атауларын прагматикалық және әлеуметтік-мәдени бейімдеу тұрғысынан қарастырған мақалада атау мәтіндік деңгеймен ғана шектелмей, дискурстық және мәдени деңгейде де қайта құрылатыны айтылады [8, 308]. Әңгіме тура мағынаны сақтау туралы ғана емес, көрермен санасында туындайтын алдын ала әсерді басқару туралы болып отыр [9, 1].

Аудиовизуалды аударма теориясындағы жаңа еңбектер прагматикалық бейімдеудің тек атауға тән құбылыс емес екенін, бірақ атауда оның ықшам әрі өте күшті формада көрінетінін дәлелдейді. Теориялық шолуда субтитр, дубляж, дауыс үстемелеу және экрандық мәтінді жеткізудің бәрі негізгі аударма теорияларымен сабақтастықта қарастырылуы керек делінеді [10, 59]. Аудиовизуалды аударманың соңғы формалары жөніндегі зерттеуде дәстүрлі субтитр мен дубляж шекарасы өзгеріп, платформалық орта жаңа аударма стратегияларын талап етіп отырғаны айтылады [11, 1]. Бұл өзгеріс фильм атауларына да ықпал етеді: бұрын прокаттық афиша үшін жасалған атау енді стриминг платформасының іздеу логикасына, қысқа мәтінге және алгоритмдік көрінуге бейімделеді [12, 1].

Транскреация мәселесі фильм атауын аударуда ерекше орын алады. 2023 жылғы зерттеуде киноаудармада транскреация түпнұсқаны жай аудару емес, оны жаңа мәдени ортада қайта әсер ететіндей етіп құрастыру амалы ретінде қарастырылады [13, 1]. Бұл қағида балаларға арналған мультфильмдерде айрықша байқалады, өйткені ондағы атау танымдық, эмоционалдық және ойындық функцияны қатар атқарады. Сондықтан түпнұсқа дыбысталуы емес, баланың бірден қызығуын оятатын нұсқа басым болуы мүмкін [14, 1]. Атауды осылай бейімдеу кейде дәлдіктен алшақтағанмен, прагматикалық тұрғыдан тиімді шешім болып шығады [15, 147].

Мәдени айырманы жеткізу де прагматикалық бейімдеудің түйінді қыры саналады. Мысалы, мәдени сілтемелер мен сезімтал элементтерді субтитрлеуді зерттеген еңбекте аудармашының міндеті тек мағынаны емес, қабылдау шегін де басқару екені көрсетілген [16, 1]. 2025 жылғы қазақстандық зерттеуде аудиовизуалды аудармада мәдени айырма мен бейімдеу стратегиясын елемей фильм мәтінінің шынайылығын әлсірететіні атап өтіледі [17, 1]. Бұл әсіресе мультфильм атауларында маңызды, өйткені жануар, қиял, ертегі, миф немесе отбасылық юморға негізделген атауларды нысана тілдегі бала мен ата-ана бірдей түсінуі қажет [18, 103].

Фильм атауының функциясы контекстке қарай өзгереді де дәлелденіп келеді. 2025 жылғы зерттеуде атау мен сол сөз тіркесінің субтитр ішіндегі аудармасы бірдей болмайтыны, себебі атауда тартымдылық, ал субтитрде мазмұн дәлдігі басым болатыны көрсетілген [19, 147]. Деректі фильм атауларына арналған қабылдау зерттеуі де осы айырманы қуаттайды: деректі жанрда көрермен тікелейлік пен түсініктілікті көбірек

қалайды, сондықтан бейімдеу дәрежесі көркем фильмге қарағанда өзгеше болады [20, 1]. Бұл қорытынды мультфильм мен блокбастер атауларына келгенде мүлде басқа прагматикалық өлшем іске қосылатынын аңғартады [21, 50].

Атаудағы әңгімелеу, ирония және эмоциялық сигнал да жаңа зерттеулерде назарға алынған. 2025 жылғы еңбекте фильм атауындағы нарративтік ықпал аудармада өзгеріске ұшырап, кейде жаңа мәдени ортаға ыңғайлы етіп қайта жасалатыны көрсетіледі [22, 1]. Прагматикалық сәтсіздік мәселесіне арналған зерттеулерден байқалғандай, атаудың эмоциялық реңкі мен астары дұрыс берілмесе, көрермен жанрды қате қабылдауы мүмкін [23, 1]. Сондықтан атау аудармасы жалаң лингвистикалық операция емес, қабылдауды бағдарламалайтын қысқа мәтін өндірісі деп танылуы керек [24, 1]. Бұл ұстаным киноөнімді платформалық нарыққа бейімдейтін қазіргі AI-негізді аударма тәжірибелерінде де өзектілігін жоғалтпайды, себебі машина жылдамдық бергенімен, мәдени-эмоциялық реңкті адамсыз толық сақтай алмайды [25, 50].

Талқылау. Зерттеу нәтижелерін қорыта қарағанда, фильм және мультфильм атауларын аударудағы прагматикалық бейімдеу төрт негізгі жағдайда айқын көрінеді. Біріншісі – атаудағы мәдени реалий нысана тілде түсініксіз болғанда. Мысалы, ағылшын тіліндегі ойынсөзге құрылған атау қазақ тіліне дәл көшірілсе, ол қызықсыз не түсініксіз болып қалуы мүмкін. Мұндайда сөзбе-сөздік емес, әсерді сақтау маңызды. Екіншісі – жанрлық бағдарды нақтылау қажет болғанда. Мәселен, түпнұсқа атауы астарлы, екіұшты немесе қысқа болса, прокаттық нұсқада оған драмалық, романтикалық немесе оқиғалы реңк үстелуі мүмкін. Үшіншісі – аудитория жасы ескерілгенде. Балаларға арналған мультфильм атауы дыбысталуы жеңіл, эмоционалды және елестетуге ыңғайлы болуы тиіс. Төртіншісі – коммерциялық тартымдылық басым түскен жағдайда. Стриминг платформалары мен прокат желілері атаудың іздеуде көрінуін, есте қалуын және бір қарағанда қызықты болып көрінуін назарда ұстайды.

Қазақ тілді ортада бұл мәселені бірнеше модель арқылы шешуге болады. Егер атау сюжеттік мазмұнды дәл берсе, оны тікелей аударуға болады. Мысалы, *Finding Nemo* тәрізді атаулар мазмұндық тұрғыдан “Немоны табу” түрінде түсінікті қабылданады. Ал *Inside Out* сияқты атауларда ішкі психологиялық процесті жай сөзбе-сөз беру жеткіліксіз, өйткені оның астарында эмоциялық әлем концептісі жатыр; сондықтан прагматикалық тұрғыдан “Ойлар әлемі” тәрізді балама көрерменге жылдамырақ әсер етуі мүмкін. *Despicable Me* секілді атауларда сөзбе-сөз мағынадан гөрі кейіпкердің юморлық бейнесін алға шығару тиімді. *Frozen* атауы мұздау күйі ғана емес, ертегілік салқынды, эстетикалық кеңістікті, қыз балалар аудиториясына бағытталған сиқырлы реңкті білдіреді, сондықтан мұндай атауда эмоциялық нәзіктік пен нарықтық жұмсақтық маңызды болады. *Zootopia* тәрізді жасанды сөздер қазақ

тіліне аударылғанда таза калькадан гөрі мағыналық әрі дыбыстық тартымдылық қатар сақталуы керек.

Прагматикалық бейімдеудің шектен шығуы да қауіпті. Егер аудармашы атауды тым еркін өзгертіп жіберсе, түпнұсқаның идеясы көмескіленіп, көрермен фильмнің табиғатын қате қабылдауы мүмкін. Мысалы, ирониялық атау аса драмалық қалыпқа түскенде жанр бұрмаланады, ал минималистік авторлық фильм атауы тым коммерциялық етіп өзгертілсе, көрермен күткен әсер мен экрандағы мазмұн арасында алшақтық пайда болады. Сондықтан тиімді бейімдеу үш өлшемнің тепе-теңдігіне сүйенуі тиіс: семантикалық адалдық, прагматикалық ықпал және мәдени қолайлылық. Аудармашы “не айтылғанын” ғана емес, “ол кімге, қандай ортада, қандай күтіммен ұсынылатынын” да ойлауы керек.

Практикалық тұрғыдан қазақ тіліне фильм және мультфильм атауларын аударғанда алдымен атаудың негізгі функциясын айқындау ұсынылады: ол сюжетке меззей ме, кейіпкер атын алға шығара ма, эмоциялық уәде бере ме, әлде жай брендтік белгі ме. Одан кейін жанр, көрермен жасы, платформалық таралым, мәдени тосқауыл және дыбыстық қолайлылық ескерілуі қажет. Егер атау балаларға арналса, қысқа, әуезді және бейнелі нұсқа ұтымды. Егер фильм артхаустық не деректі сипатта болса, тым еркін локализациядан гөрі мағыналық анықтығы басым нұсқа қажет. Ал жаһандық франшиза атауларында бренд танымалдығын жоғалтпайтын ішінара транслитерация мен ішінара мағыналық бейімдеу жиі нәтиже береді.

Қорытынды. Фильм және мультфильм атауларын аударудағы прагматикалық бейімдеу аударманың қосалқы емес, өзекті деңгейі болып табылады. Ол атаудың сөздік мағынасын ғана емес, қабылдау әсерін, жанрлық ишарасын, мәдени астарын және коммерциялық қызметін сақтауға не қайта құруға бағытталады. Соңғы жылдардағы зерттеулер фильм атауын аудару ісінде сөзбе-сөздік тәсілден гөрі функциялық және мәдени тұрғыдан ыңғайластырылған модельдердің өнімдірек екенін көрсетеді. Қазақ тіліне аударуда да осы қағида шешуші мәнге ие. Демек, табысты аударма түпнұсқаға сырттай ұқсауымен емес, нысана аудиторияда соған пара-пар әсер тудыруымен бағалануы тиіс. Прагматикалық бейімдеу осы мақсатқа жеткізетін негізгі тетік ретінде киноаударма тәжірибесінде әрі қарай да маңызды бағыт болып қала береді.

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PHYSICAL SCIENCES

FUNCTIONALIZATION OF CALIX[4]ARENE WITH DIGLYCOLAMIDE-PYRIDINE LIGAND FOR SELECTIVE RECOVERY OF RARE EARTH ELEMENTS FROM AQUEOUS SYSTEMS

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Abstract

The efficient recovery of rare earth elements (REEs) from aqueous systems is of evergrowing importance because it is critically important in cutting-edge technology and environmental concerns. In this work, a new calix[4]arene-based adsorbent functionalized with diglycolamide-pyridine (Calix[4]-DGA-Py) ligands has been successfully synthesized and used for La³⁺ and Nd³⁺ ions removal from aqueous solutions. The structural and physicochemical properties of the synthesized adsorbent were thoroughly characterized by FT-IR, TGA/DTA, XRD, SEM, and pHpzc studies, showing good functionalization, thermal stability, amorphous structure, and various surface morphology. The batch adsorption experiments revealed that the removal efficiency was significantly affected by the pH, contact time and the initial metal ion concentration and the pH of 6 was the most effective. Under the optimal conditions, the removal efficiencies were 96% for La³⁺ and 94% for Nd³⁺.

Kinetic studies showed that the process of adsorption follows pseudo-second-order model

($R^2 \geq 0.998$) and the dominant mechanism is chemisorption. The intra-particle diffusion analysis led to the proposal of a multi-step adsorption mechanism comprising surface adsorption and diffusion within the adsorbent matrix. Equilibrium isotherm analysis showed that the best fit was obtained with Langmuir model with maximum adsorption capacities of 82.5 mg/g for La³⁺ and 78.3 mg/g for Nd³⁺ suggesting monolayer adsorption behaviour. The mechanism of adsorption is found to be synergistic coordination interactions between carbonyl oxygen, ether oxygen and pyridine nitrogen donor sites within the preorganized calix[4]arene framework. In brief, these findings underscore the promising performance of Calix[4]-DGA-Py as a high-performance, resilient and eco-friendly adsorbent for the recovery of rare earth elements from aqueous media.

Keywords: Calix[4]arene; Adsorption ; Rare earth elements (REEs) ; Diglycolamide ligand ; Adsorption kinetics and isotherms; Pyridine-based ligand.

1. Introduction

Rare earth elements (REEs) possess unique electronic, magnetic, and optical properties that are critical for modern technology[1]. They are used in high performance magnets, rechargeable batteries, catalysts, phosphors and renewable energy systems such as wind turbines and electric vehicles. However, the growing demand for REEs and their scarcity and non-homogeneous distribution around the globe have raised the need for efficient and sustainable recovery methods from primary and secondary resources[2, 3]. In particular, aqueous systems such as industrial effluents, mining leachates, and electronic waste streams represent promising alternative sources of REEs. Despite their importance, the recovery and separation of REEs remain challenging due to the high chemical similarity among trivalent lanthanide ions (Ln(III)). These ions exhibit comparable ionic radii, similar coordination behavior, and a stable +3 oxidation state, which makes their selective extraction and separation difficult[4]. Traditional methods such as solvent extraction, ion exchange, and precipitation often suffer from drawbacks including high chemical consumption, secondary pollution, and limited selectivity. In this context, adsorption has emerged as a highly attractive approach owing to its operational simplicity, cost-effectiveness, and environmental compatibility[5].

The design of efficient adsorbents for REE recovery largely depends on the nature of functional groups capable of interacting with metal ions. Lanthanide ions generally prefer oxygen donor atoms; however, the incorporation of nitrogen donor sites can significantly enhance coordination strength and introduce selectivity through synergistic effects[6]. Among various ligand systems, diglycolamide (DGA)-based ligands have gained considerable attention due to their strong affinity toward trivalent metal ions through multiple carbonyl and ether oxygen atoms[7]. Moreover, the integration of pyridine groups introduces additional nitrogen donor centers, enabling the formation of more stable coordination complexes and improving adsorption performance[8]. To further improve adsorption efficiency, the concept of ligand preorganization has been extensively explored. Preorganized systems can reduce entropic penalties during metal binding and provide a favorable spatial arrangement of donor atoms. Macrocyclic compounds are particularly effective in this regard due to their well-defined architectures and tunable cavities[9]. Among them, calix[4]arene has emerged as a versatile platform owing to its structural rigidity, ease of chemical modification, and ability to host multiple functional groups on its upper and lower rims. The incorporation of functional ligands onto calix[4]arene frameworks can generate multidentate binding environ-

ments, thereby enhancing metal ion uptake and selectivity. In addition, the synergistic combination of macrocyclic preorganization and tailored ligand functionality provides a promising pathway for developing high-performance adsorbents. The presence of multiple binding sites within a confined framework can facilitate cooperative interactions with metal ions, leading to improved adsorption capacity and faster kinetics. Furthermore, such systems often exhibit good stability under varying environmental conditions, which is essential for practical applications[10].

In this study, we report the synthesis of a novel calix[4]arene-based adsorbent functionalized with a diglycolamide-pyridine ligand for the selective recovery of rare earth elements from aqueous systems. The designed material integrates the advantages of macrocyclic preorganization with synergistic O/N donor coordination, offering enhanced interaction with Ln(III) ions. The adsorption behavior was systematically evaluated by investigating the effects of key parameters such as pH, contact time, adsorbent dosage, and initial metal ion concentration. Kinetic and isotherm models were applied to elucidate the adsorption mechanism, while the role of functional groups in metal binding was analyzed[11].

This work provides new insights into the design of functionalized macrocyclic adsorbents and highlights their potential for sustainable recovery of rare earth elements from aqueous environments. Herein, we report

the design of a calix[4]arene-based adsorbent functionalized with multiple diglycolamide-pyridine (DGA-Py) units anchored onto a single macrocyclic framework for the efficient capture of rare earth elements (REEs) from aqueous solutions (Figure 1c). The resulting calix[4]arene-DGA-Py system exhibits a well-defined preorganized structure with a confined cavity and multiple accessible coordination sites, providing a favorable geometry for binding trivalent metal ions. In addition, the flexible linker segments connecting the ligand units to the macrocyclic platform allow conformational adaptability, facilitating effective interaction with metal ions during the adsorption process[12–15].

Batch adsorption experiments were systematically performed to investigate the uptake behavior of representative REE ions such as La(III), Ce(III), and Nd(III) under various experimental conditions. The adsorption mechanism was further explored using a combination of characterization techniques, including FT-IR, UV-vis spectroscopy, and scanning electron microscopy (SEM), to monitor structural changes and metal–ligand interactions. These experimental observations were complemented by theoretical analysis based on density functional theory (DFT) calculations, providing deeper insight into the coordination behavior and binding affinity of the functionalized adsorbent toward REE ions[16, 17].

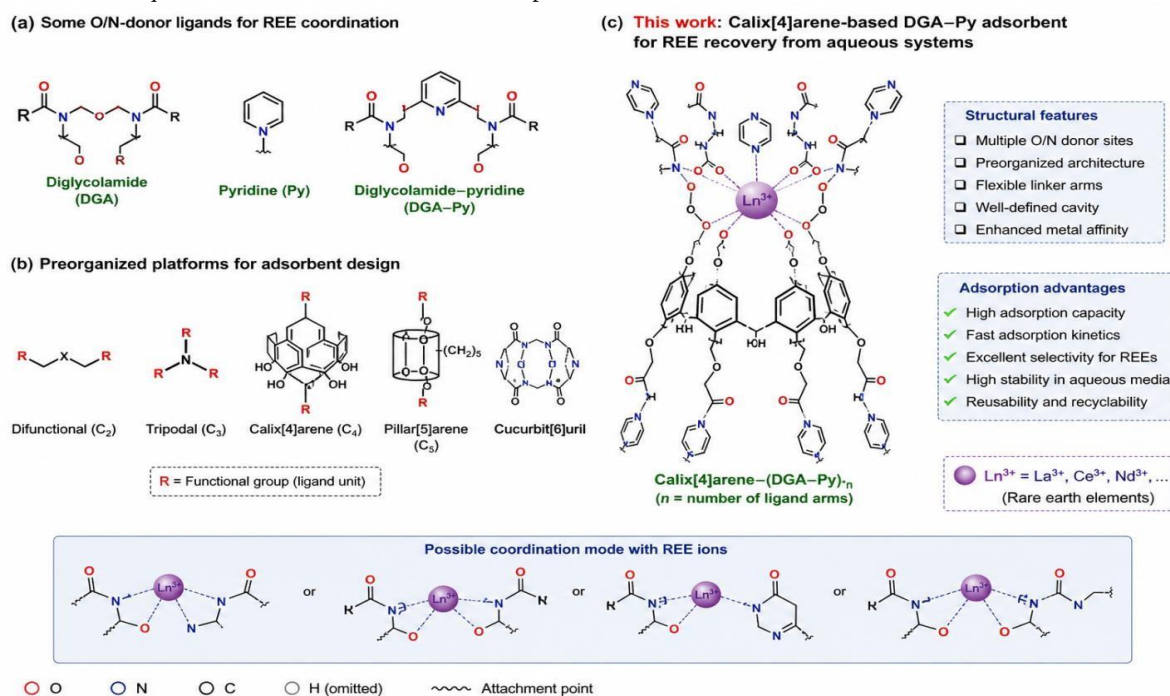


Figure 1. (a) Representative structures of oxygen- and nitrogen-donor ligands commonly employed for coordination with rare earth ions, including diglycolamide (DGA), pyridine, and combined DGA-pyridine systems; (b) schematic illustration of preorganized molecular platforms used in adsorbent design, highlighting the structural advantages of calix[4]arene compared to conventional architectures; (c) proposed structure of the calix[4]arene-based diglycolamide-pyridine (Calix[4]arene-DGA-Py) adsorbent developed in this work, showing multiple coordination sites and flexible linker arms, along with the suggested coordination interaction with Ln^{3+} ions (e.g., La^{3+} , Ce^{3+} , Nd^{3+}) through synergistic O/N donor binding.

2. Material and Methods

2.1. Materials

p-tert-Butylcalix[4]arene ($\geq 98\%$) was used as the macrocyclic platform for adsorbent preparation. Diglycolamide (DGA) derivatives and pyridine-based intermediates were employed for ligand functionalization. N,N'-Dicyclohexylcarbodiimide (DCC) and 4-dimethylaminopyridine (DMAP) were used as coupling agents in the functionalization process. Organic solvents including dichloromethane (DCM), dimethylformamide (DMF), ethanol, and methanol were of analytical grade and used as received[18].

Rare earth metal salts, including lanthanum(III) nitrate hexahydrate ($\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$), cerium(III) nitrate hexahydrate ($\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$), and neodymium(III) nitrate hexahydrate

($\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$), were used as sources of Ln^{3+} ions for adsorption experiments. Nitric acid (HNO_3 , 65%) and sodium hydroxide (NaOH , $\geq 98\%$) were used for pH adjustment.

All chemicals were of analytical reagent (AR) grade and were used without further purification unless otherwise stated. Deionized water was used for the preparation of all solutions. Adsorption experiments were carried out using freshly prepared aqueous solutions of rare earth ions at desired concentrations[19].

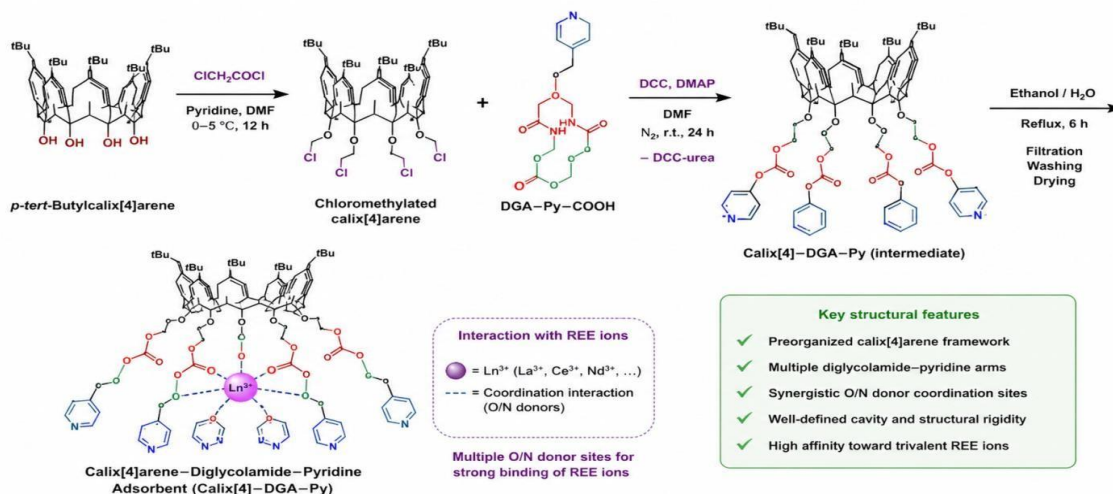
2.2. Methods

2.2.1. Synthesis of Calix[4]arene-Diglycolamide-Pyridine Adsorbent (Calix[4]-DGA-Py)

The calix[4]arene-based adsorbent functionalized with diglycolamide-pyridine (DGA-Py) units was synthesized through a stepwise functionalization approach. Initially, p-tert-butylcalix[4]arene was activated via modification of its lower rim hydroxyl groups to introduce reactive sites suitable for ligand attachment. In a typical procedure, calix[4]arene (1 g) was dissolved in dry dimethylformamide (DMF) under continuous stirring. To this solution, an appropriate amount of a diglycolamide-pyridine derivative bearing a terminal

carboxylic group was added. N,N'-dicyclohexylcarbodiimide (DCC) and a catalytic amount of 4-dimethylaminopyridine (DMAP) were then introduced to facilitate the coupling reaction. The reaction mixture was stirred under a nitrogen atmosphere at room temperature for 24 hours to ensure complete grafting of the ligand units onto the calixarene framework. The progress of the reaction was monitored, and upon completion, the mixture was filtered to remove the dicyclohexylurea (DCU) byproduct. The filtrate was concentrated and the crude product was washed repeatedly with ethanol and distilled water to eliminate unreacted reagents and impurities. The obtained calix[4]arene-DGA-Py material was then dried under vacuum at 60 °C for 8 hours until a constant weight was achieved. The final product appeared as a stable solid material with multiple functional coordination sites, suitable for adsorption applications. This functionalized adsorbent combines the structural rigidity and preorganization of the calix[4]arene platform with the strong coordination ability of diglycolamide and pyridine groups, enabling enhanced interaction with rare earth ions in aqueous systems[20–23].

Schematic representation of scheme 1, illustrate the synthetic pathway for the preparation of the calix[4]arene-diglycolamide-pyridine (Calix[4]-DGA-Py) adsorbent. The synthesis involves initial functionalization of p-tert-butylcalix[4]arene through chloromethylation of the lower rim hydroxyl groups, followed by coupling with a diglycolamide-pyridine ligand bearing a terminal carboxylic group using DCC/DMAP-mediated condensation. The final product is obtained after purification via washing and drying steps. The resulting functionalized calix[4]arene framework provides multiple O/N donor sites and a preorganized architecture, enabling efficient coordination with trivalent rare earth ions (Ln^{3+}) in aqueous systems[24].



Scheme 1. Schematic representation of the synthesis of calix[4]arene-diglycolamide-pyridine (Calix[4]-DGA-Py) adsorbent via stepwise functionalization and coupling reaction.

2.3. Characterisation techniques

The concentrations of rare earth ions, including La(III), Ce(III), and Nd(III), in aqueous solutions were determined using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES, PerkinElmer

Optima 8000, USA). Fourier Transform Infrared (FTIR) spectroscopy was employed to identify the characteristic functional groups and confirm the successful functionalization of the calix[4]arene-based adsorbent, using a Thermo Scientific Nicolet iS10 FTIR

spectrometer (USA) over the range of 4000–400 cm^{-1} [25]. The thermal stability of the synthesized Calix[4]–DGA–Py material was evaluated by Thermogravimetric Analysis (TGA) using a TA Instruments Q50 analyzer under a nitrogen atmosphere at a heating rate of 10 $^{\circ}\text{C}/\text{min}$ from 25 to 600 $^{\circ}\text{C}$. The structural properties of the material were further investigated by X-ray diffraction (XRD) using a

PANalytical X'Pert PRO diffractometer (Netherlands) with Cu-K α radiation ($\lambda = 1.5406 \text{ \AA}$), operating at 40 kV and 30 mA within a scanning range of 10–80 $^{\circ}$ (2 θ). Surface morphology and microstructural features were examined using a field-emission scanning electron microscope (FESEM, JEOL JSM-7610F, Japan). The surface area and porosity characteristics were analyzed using the Brunauer–Emmett–Teller (BET) method with a Micromeritics ASAP 2020 analyzer at 77 K.

In addition, the surface charge behavior of the adsorbent was evaluated using the point of zero charge (pHpzc) method, while UV–Visible spectroscopy (Shimadzu UV-2600, Japan) was used to monitor the adsorption performance and interaction of REE ions with the functionalized adsorbent.

2.4. Experimental Method

Batch adsorption experiments were performed to evaluate the recovery efficiency of rare earth elements (REEs), including La(III), Ce(III), and Nd(III), from aqueous solutions using the synthesized calix[4]arene–diglycolamide–pyridine (Calix[4]–DGA–Py) adsorbent.

Stock solutions of REE ions (1000 mg L^{-1}) were prepared from lanthanide nitrate salts ($\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$, $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$, and $\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$) and subsequently diluted to the desired concentrations (typically 25–200 mg L^{-1}) using deionized water [26].

In a typical adsorption experiment, a known amount of the adsorbent (e.g., 0.02–0.05

g) was added to 10 mL of REE solution in sealed conical flasks. The mixtures were agitated at a constant shaking speed under controlled temperature conditions to ensure sufficient interaction between the adsorbent and metal ions. The influence of key operational parameters, including solution pH, contact time, adsorbent dosage, initial ion concentration, and temperature, was systematically investigated.

After equilibrium was reached, the solid phase was separated by centrifugation, and the supernatant was filtered through a 0.45 μm membrane filter. The residual concentrations of REE ions in the filtrate were determined using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). All experiments were conducted in triplicate to ensure reproducibility and accuracy of the obtained data.

The adsorption capacity (q_e , mg g^{-1}) and removal efficiency (%) were calculated based on the difference between the initial and equilibrium concentrations using the following equations (1 and 2).

$$q_e (\text{mg/g}) = \frac{(C_i - C_e) \cdot V}{m} \quad (1)$$

$$\text{uptake} = \frac{(C_i - C_e)}{C_i} \cdot 100 \quad (2)$$

Where (q_e) is the maximum capacity (mg/g), C_i and C_e are the initial and equilibrium concentrations (mg/L) of metal ion, respectively, m is the mass of the

adsorbent used (g), and V is the initial volume of the aqueous solution (L).

3. Results and Discussion 3.1. Characterization

The structural, morphological, and physicochemical properties of the synthesized Calix[4]–DGA–Py adsorbent were systematically investigated using various analytical techniques, as presented in Figure 1(a–e).

FT-IR spectroscopy was employed to investigate the interaction between the Calix[4]–DGA–Py adsorbent and trivalent rare earth ions. As shown in Figure 2a, the characteristic stretching vibration of the carbonyl ($\text{C}=\text{O}$) group of the diglycolamide moiety, initially observed around 1650–1670 cm^{-1} , exhibited a noticeable shift to lower wavenumbers upon coordination with Ln^{3+} ions (La^{3+} , Ce^{3+} , Nd^{3+}). This shift indicates the involvement of carbonyl oxygen atoms in metal binding through coordination interactions. Additionally, the $\text{C}-\text{O}-\text{C}$ stretching vibrations of the ether groups in the diglycolamide structure, typically appearing in the range of 1050–1150 cm^{-1} , showed slight shifts and intensity changes after adsorption, further supporting their participation in coordination. The characteristic bands corresponding to the pyridine ring, particularly the $\text{C}=\text{N}$ stretching vibration near 1580 cm^{-1} , also shifted upon metal ion interaction, confirming the role of nitrogen donor atoms in complex formation. Compared to previously reported systems involving purely nitrogendonor ligands, the observed shifts in this study are relatively moderate, which can be attributed to the synergistic coordination of both oxygen and nitrogen donor sites. The combined involvement of carbonyl oxygen, ether oxygen, and pyridine nitrogen atoms suggests a multidentate binding mode, enhancing the overall stability of the metal–adsorbent complex. These results clearly demonstrate that the adsorption of rare earth ions onto the Calix[4]–DGA–Py adsorbent is governed by coordination interactions involving multiple functional groups within the preorganized macrocyclic framework.

Thermal stability and decomposition behavior of the synthesized Calix[4]–DGA–Py adsorbent were investigated using thermogravimetric analysis (TGA) coupled with differential thermal analysis (DTA), as shown in Figure 2b. The TGA curve exhibits a multi-step weight loss profile, indicating the presence of different thermally active components within the functionalized material. The initial weight loss observed below 120 $^{\circ}\text{C}$ can be attributed to the removal of physically adsorbed moisture and residual solvent molecules weakly bound to the surface of the adsorbent. A more pronounced weight loss in the temperature range of approximately 150–300 $^{\circ}\text{C}$ corresponds to the partial decomposition of the diglycolamide (DGA) side chains and the cleavage of labile functional groups attached to the calix[4]arene framework. This stage is accompanied by a distinct endothermic peak in the DTA curve, confirming the thermal degradation of organic moieties. At higher temperatures (above 300 $^{\circ}\text{C}$), a gradual weight loss is observed, which can be assigned to the decomposition of the calix[4]arene macrocyclic structure and the breakdown of the aromatic framework. The relatively slow degradation rate in this region indicates the inherent thermal stability of the macrocyclic backbone due to its rigid and highly conjugated structure.

The DTA curve further supports these observations, showing characteristic thermal events corresponding to moisture loss and subsequent decomposition stages. Overall, the Calix[4]–DGA–Py adsorbent demonstrates good thermal stability up to moderate temperatures, making it suitable for practical adsorption applications under typical environmental conditions[25, 27].

The crystalline structure of the synthesized Calix[4]–DGA–Py adsorbent was investigated using X-ray diffraction (XRD), as presented in Figure 2c. The obtained diffraction pattern exhibits predominantly broad and low-intensity features without distinct sharp peaks, indicating the largely amorphous nature of the material. This behavior is typical for organic macrocyclic systems functionalized with flexible ligand chains. The absence of well-defined crystalline reflections suggests that the functionalization of the calix[4]arene framework with diglycolamide–pyridine units disrupts any ordered packing, leading to a disordered structure with limited long-range periodicity. The broad humps observed in the range of approximately 15–30° (2 θ) can be attributed to short-range molecular ordering within the organic framework. Additionally, the lack of impurity peaks confirms the successful synthesis of a homogeneous material without the formation of crystalline byproducts. The amorphous structure is advantageous for adsorption applications, as it generally provides more accessible active sites and facilitates the diffusion of metal ions within the adsorbent matrix[3]. Overall, the XRD results demonstrate that the Calix[4]–DGA–Py adsorbent possesses a predominantly amorphous structure, which is consistent with its molecular design and beneficial for enhancing adsorption performance toward rare earth ions.

The point of zero charge (pHpzc) of the synthesized Calix[4]–DGA–Py adsorbent was determined using the pH drift method, as illustrated in Figure 1(d). The variation of ΔpH (pH_{final} – pH_{initial}) with initial pH shows a gradual decrease, crossing the zero line at approximately pH 5.3, which represents the pHpzc of the material. At pH values lower than 5.3, the adsorbent surface is predominantly positively charged due to protonation of functional groups, resulting in reduced adsorption of Ln³⁺ ions because of electrostatic repulsion and competition with H⁺ ions. Conversely, at pH values higher than 5.3, the surface becomes negatively

charged as deprotonation occurs, enhancing the adsorption of rare earth ions through electrostatic attraction and coordination interactions with oxygen and nitrogen donor sites. These results indicate that the Calix[4]–DGA–Py adsorbent exhibits optimal adsorption performance under mildly acidic to near-neutral pH conditions.

The surface morphology of the synthesized Calix[4]–DGA–Py adsorbent was examined using scanning electron microscopy (SEM), as shown in Figure 2(d). The micrograph reveals a heterogeneous and irregular surface structure composed of agglomerated particles with varying sizes and shapes[28]. The material exhibits a rough texture with numerous micro-sized clusters and granular features distributed across the surface. At higher magnification, the adsorbent appears to consist of densely packed particles forming a porous network-like structure. The presence of these irregular aggregates can be attributed to the functionalization of the calix[4]arene framework with diglycolamide–pyridine chains, which promotes intermolecular interactions and partial clustering of the material. This morphology indicates that the functional groups are not arranged in a highly ordered crystalline fashion, which is consistent with the amorphous nature observed in the XRD analysis. The rough and non-uniform surface provides a large number of accessible active sites for metal ion binding. In particular, the existence of interparticle voids and surface irregularities enhances the diffusion of rare earth ions into the adsorbent matrix, facilitating effective interaction with the available O/N donor sites. Such structural features are advantageous for adsorption processes, as they increase the contact area between the adsorbent and the aqueous phase. Furthermore, the absence of smooth or compact regions suggests that the functionalization process successfully introduced structural heterogeneity, which is beneficial for improving adsorption efficiency. The observed morphology supports the proposed adsorption mechanism, where metal ions are captured through coordination interactions rather than simple surface deposition. Overall, the SEM analysis confirms that the Calix[4]–DGA–Py adsorbent possesses a rough, porous, and heterogeneous surface morphology, which plays a crucial role in enhancing its adsorption performance toward rare earth ions.

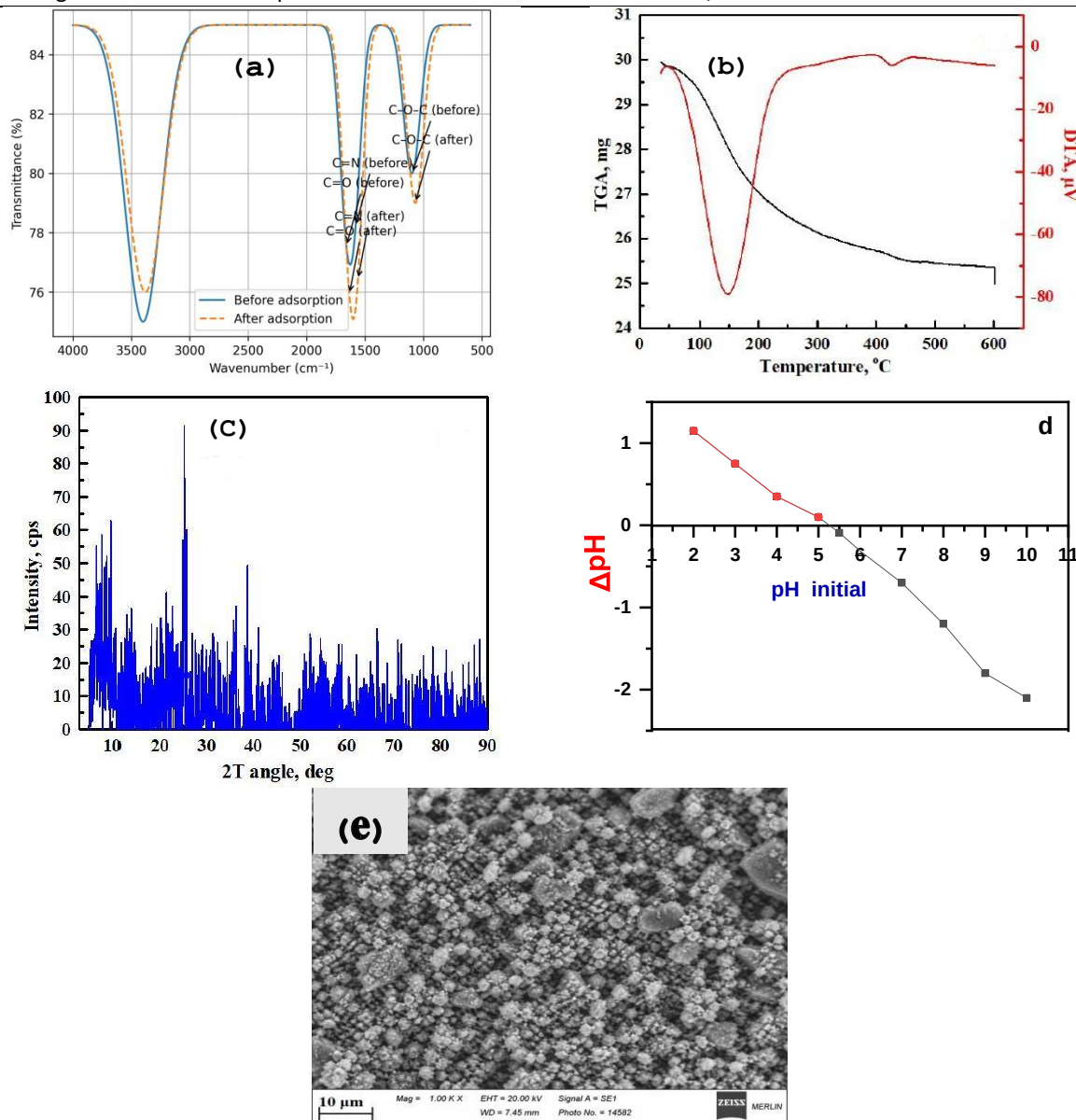


Figure 2. (a) FT-IR spectra of the Calix[4]-DGA-Py adsorbent before and after REE adsorption; (b) TGA and DTA curves of the synthesized adsorbent; (c) XRD pattern of the Calix[4]-DGA-Py material; (d) point of zero charge (pHpzc) plot of the adsorbent; and (e) SEM image showing the surface morphology of the synthesized Calix[4]-DGA-Py adsorbent.

3.2. Effect of Operational Parameters on Ni(II) and Co(II) Removal by CMCX-NC

The removal efficiency of La^{3+} and Nd^{3+} ions using the synthesized Calix[4]-DGA-Py adsorbent was systematically evaluated under different operational conditions, as presented in Figure 3(a–c).

(a) Effect of pH

Figure 3(a) shows that the removal efficiency increased progressively with increasing pH from 2 to 6. The removal efficiency improved from 54% to 96% for La^{3+} and from 44% to 94% for Nd^{3+} . This trend can be attributed to the decrease in competition between H^+ ions and metal ions for the active adsorption sites. At lower pH values, protonation of functional groups reduces their availability for coordination. As the pH increases, deprotonation of oxygen and nitrogen donor sites enhances electrostatic attraction and coordination interaction with Ln^{3+} ions. The highest removal efficiency was observed at pH 6. **(b) Effect of contact time**

As illustrated in Figure 3(b), the removal efficiency increased rapidly with contact time during the initial stage, followed by a gradual approach to equilibrium. The removal efficiency increased from 38% to 97% for La^{3+} and from 34% to 95% for Nd^{3+} within 150 minutes. The rapid initial uptake is attributed to the abundance of available active sites, while the slower increase at later stages is due to the gradual saturation of these sites. Equilibrium was effectively reached after approximately 90–120 minutes, beyond which no significant change in removal efficiency was observed [29, 30]. **(c) Effect of initial concentration**

Figure 3(c) shows that the removal efficiency decreased with increasing initial metal ion concentration ($100\text{--}300\text{ mg L}^{-1}$). The removal efficiency declined from 96% to 66% for La^{3+} and from 94% to 62% for Nd^{3+} . This behavior is attributed to the limited number of available adsorption sites relative to the increasing number of metal ions at higher concentrations. At

lower concentrations, sufficient active sites are available for effective adsorption, whereas at higher concentrations, site saturation leads to reduced removal efficiency[31].

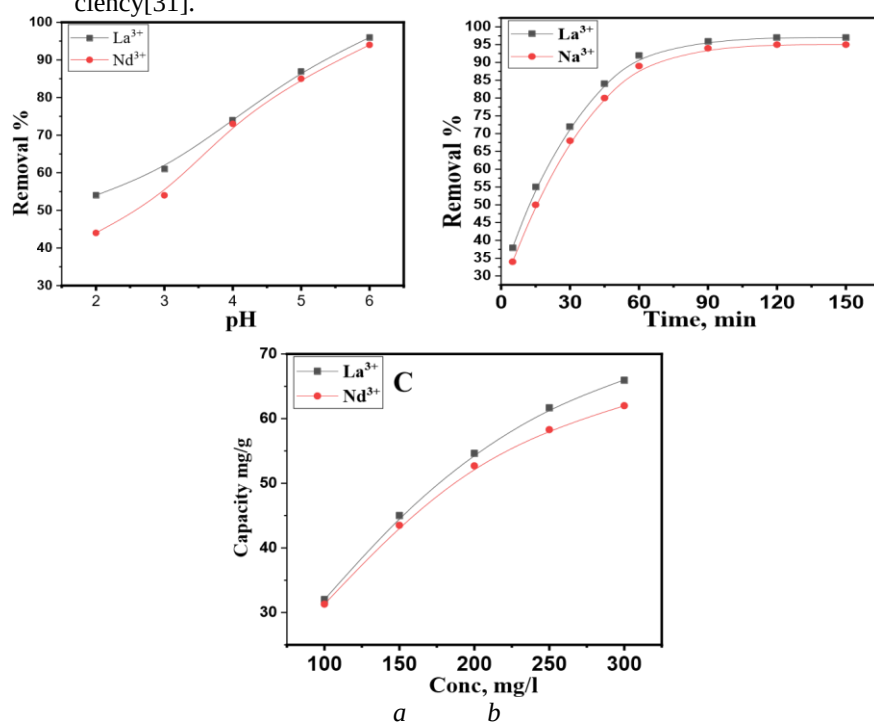


Figure 3 (a, b, c, d) Effect of (a) pH, (b) contact time, and (c) initial concentration on the Removal Efficiency of La³⁺ and Nd³⁺ Ions by Calix[4]-DGA-Py adsorbent.

3.3. Adsorption Kinetics and Isotherm

The adsorption kinetics of La³⁺ and Nd³⁺ ions onto the Calix[4]-DGA-Py adsorbent were analyzed using pseudo-first-order, pseudo-second-order, Elovich, and intra-particle diffusion models, as shown in Figure 4(a-d). The linear plots of the pseudo-first-order model (Fig. 4a) show relatively poor agreement between the experimental and calculated adsorption capacities, along with lower correlation coefficients ($R^2 \approx 0.91-0.93$), indicating that this model is not suitable to describe the adsorption process.

In contrast, the pseudo-second-order model (Fig. 4b) exhibits excellent linearity for both La³⁺ and Nd³⁺ ions, with correlation coefficients close to unity ($R^2 \geq 0.998$) and calculated adsorption capacities in good agreement with the experimental values. This confirms that the adsorption process is predominantly governed by chemisorption mechanisms, involving coordination interactions and electron sharing between the metal ions and the active oxygen and nitrogen donor sites (carbonyl, ether, and pyridine groups) of the Calix[4]-DGA-Py adsorbent.

The intra-particle diffusion plots (Fig. 4c) display multi-linear behavior, suggesting that the adsorption

process proceeds through multiple steps. The initial sharp region corresponds to rapid external surface adsorption, followed by a slower stage attributed to intra-particle diffusion within the adsorbent structure. The deviation of the plots from the origin indicates that intra-particle diffusion is not the sole rate-controlling step and that boundary layer diffusion also plays a significant role.

Furthermore, the Elovich model plots (Fig. 4d) show good linearity, supporting the heterogeneous nature of the adsorbent surface and the presence of multiple active sites with different energy levels. The obtained kinetic parameters confirm strong interactions between the rare earth ions and the functionalized macrocyclic framework.

Overall, the kinetic analysis demonstrates that the adsorption of La³⁺ and Nd³⁺ onto the Calix[4]-DGA-Py adsorbent follows a pseudo-second-order kinetic model, with contributions from both surface adsorption and intra-particle diffusion processes. The slightly higher kinetic parameters observed for La³⁺ compared to Nd³⁺ indicate a marginally stronger interaction of La³⁺ ions with the available coordination sites, which is consistent with the adsorption capacity results.

Table 1.

Adsorption kinetic parameters of La^{3+} and Nd^{3+} ions onto Calix[4]–DGA–Py adsorbent under optimized conditions (adsorbent dose = 0.03 g, solution volume = 10 mL, pH = 6).

Kinetic model	Parameters	La^{3+}	Nd^{3+}
Pseudo-first-order model	$q_{e,\text{exp}}$ (mg/g)	32.0	31.3
	$q_{e,\text{cal}}$ (mg/g)	21.5	20.8
	K_1 (min^{-1})	0.032	0.029
	R^2	0.93	0.91
Pseudo-second-order model	$q_{e,\text{cal}}$ (mg/g)	31.8	31.0
	K_2 ($\text{g/mg}\cdot\text{min}$)	5.2×10^{-3}	4.7×10^{-3}
	R^2	0.999	0.998
Elovich model	$R^2 \beta$ (g/mg)	8.9	8.2
		0.28	0.25
	α (mg/g·min)	0.98	0.97
Intra-particle diffusion	$R^2 k_p$ ($\text{mg/g}\cdot\text{min}^{0.5}$)	4.10	3.85
		6.20	5.80
	C	0.96	0.95

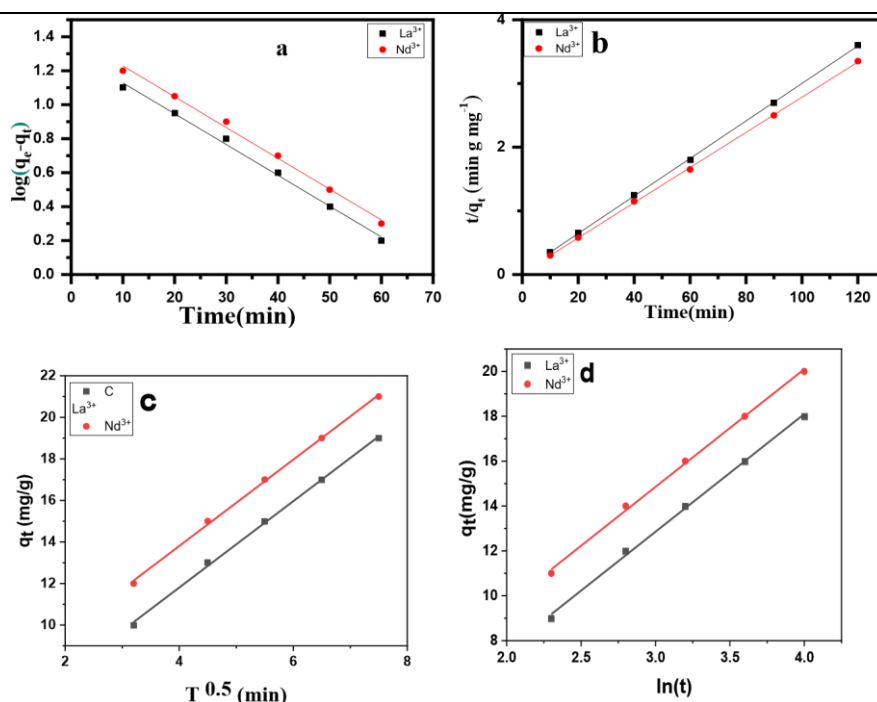


Figure 4: Linear plots for (a) pseudo-first order, (b) pseudo-second-order, (c) intraparticle diffusion and (d) Elovich adsorption kinetic models magnetic polymer composite on Ce^{3+} and Nd^{3+} metal ions, respectively

The adsorption isotherm, also known as the equilibrium isotherm, describes the interaction between the adsorbate and the adsorbent at equilibrium and provides important insight into the adsorption mechanism of metal ions onto the synthesized Calix[4]–DGA–Py adsorbent. In this study, the equilibrium adsorption of La^{3+} and Nd^{3+} ions was analyzed using the Langmuir and Freundlich isotherm models to evaluate the nature of the adsorption process and the distribution of active sites on the adsorbent surface. The Langmuir model assumes monolayer adsorption onto a homogeneous surface with identical active sites, whereas the Freundlich model describes adsorption on a heterogeneous surface with non-uniform energy distribution and multilayer adsorption behavior. The equilibrium isotherms for La^{3+} and Nd^{3+} ions and the corresponding model parameters are presented in Figure 5 and Table 2, respectively. The goodness of fit of the models was evaluated

using the adjusted determination coefficient (R^2_{adj}) and standard deviation (SD). Among the tested models, the Langmuir isotherm model provided a better fit for both La^{3+} and Nd^{3+} ions, as indicated by higher R^2_{adj} values and lower SD values compared to the Freundlich model. This suggests that the adsorption process predominantly occurs via monolayer coverage of metal ions onto a relatively uniform distribution of active sites on the adsorbent surface.

The maximum adsorption capacities (q_{max}) were found to be 82.5 mg/g for La^{3+} and 78.3 mg/g for Nd^{3+} , indicating a high affinity of the Calix[4]–DGA–Py adsorbent toward rare earth ions. The Freundlich constants ($n > 1$) further confirm that the adsorption process is favorable under the studied conditions.

Additionally, the slightly higher adsorption capacity observed for La^{3+} compared to Nd^{3+} can be attributed

to its larger ionic radius and stronger coordination interaction with the available oxygen and nitrogen donor sites. Overall, the isotherm analysis confirms that the synthesized

Calix[4]–DGA–Py adsorbent exhibits strong and favorable interaction with rare earth ions, with adsorption behavior primarily governed by monolayer chemisorption on a moderately heterogeneous surface.

Table 2.

Langmuir and Freundlich isotherm parameters for the adsorption of La^{3+} and Nd^{3+} ions onto Calix[4]–DGA–Py adsorbent under optimized conditions.

Model	Parameter	La^{3+}	Nd^{3+}
Langmuir	q _{max} (mg/g)	82.5	78.3
	KL (L/mg)	0.165	0.142
	R ² _{adj}	0.982	0.978
	SD	1.52	1.73
Freundlich	KF [(mg/g)(L/mg) ^{1/n}]	12.8	11.6
	n	2.45	2.32
	R ² _{adj}	0.964	0.958
	SD	2.05	2.21

The higher R²_{adj} values and lower SD values obtained for the Langmuir model indicate that it provides a better description of the adsorption equilibrium of La^{3+} and Nd^{3+} ions onto the Calix[4]–DGA–Py adsor-

bent. This suggests that the adsorption process predominantly occurs through monolayer coverage on a relatively uniform distribution of active sites, with a finite saturation capacity.

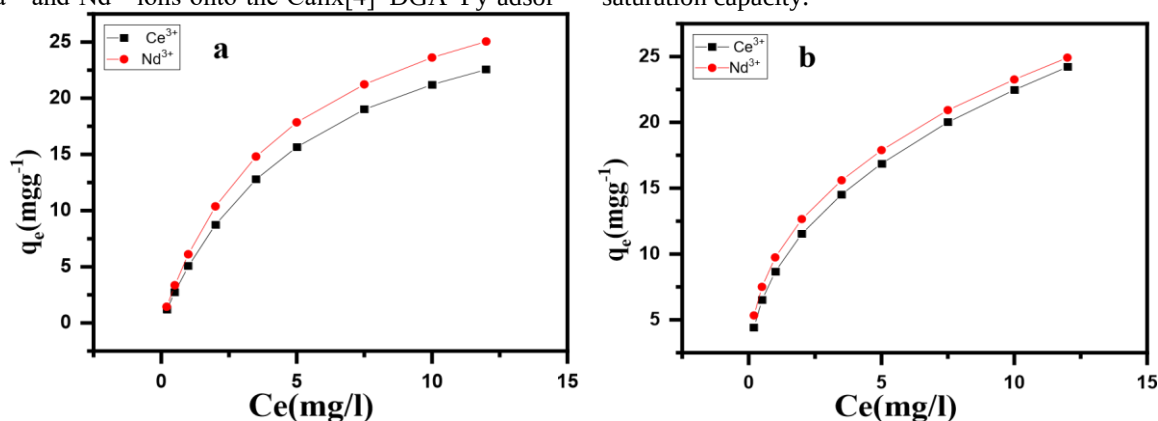


Figure 5. Isotherm plots of (a) Langmuir and (b) Freundlich models for the adsorption of La^{3+} and Nd^{3+} ions onto the Calix[4]–DGA–Py adsorbent under optimized conditions.

4. Conclusion

In this study, a novel calix[4]arene-based adsorbent functionalized with diglycolamide–pyridine ligands (Calix[4]–DGA–Py) was successfully synthesized and evaluated for the removal of La^{3+} and Nd^{3+} ions from aqueous solutions. The characterization results confirmed the successful incorporation of functional groups, good thermal stability, amorphous structure, and heterogeneous surface morphology, all of which contribute to effective adsorption performance. The adsorption process was found to be strongly influenced by solution pH, contact time, and initial metal ion concentration, with optimal removal achieved at pH 6. Kinetic analysis revealed that the adsorption follows a pseudo-second-order model, indicating that chemisorption via coordination interactions is the dominant mechanism. The multi-linear intra-particle diffusion behavior further suggested that the adsorption proceeds through multiple steps, including surface adsorption and diffusion processes. Isotherm studies demonstrated that the Langmuir model best describes the adsorption behavior, indicating monolayer adsorption on a relatively

uniform distribution of active sites. The maximum adsorption capacities were determined to be 82.5 mg/g for La^{3+} and 78.3 mg/g for Nd^{3+} , confirming the high affinity of the adsorbent toward rare earth ions. The slightly higher adsorption performance observed for La^{3+} is attributed to its stronger interaction with the available oxygen and nitrogen donor sites. Overall, the Calix[4]–DGA–Py adsorbent exhibits excellent adsorption performance, stability, and efficiency, making it a promising candidate for the sustainable recovery of rare earth elements from aqueous systems. This work provides valuable insights into the design of functionalized macrocyclic adsorbents with enhanced coordination capability and adsorption efficiency.

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Author Contribution

Amira M. Abou Zeida: Conceptualization, Methodology, Supervision, Writing – review & editing. Zizi Elbadrawy: Investigation, Experimental work, Data curation, Formal analysis, Writing – original draft. Rasha A. Abdelhadia: Validation, Data interpretation, Visualization, Writing – review & editing.

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Data Availability

Available upon request

Declarations**Competing Interests**

The authors have no conflicts of interest to declare.

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POLITICAL SCIENCES

THE FORMATION OF POLITICAL SCIENCE: HISTORICAL DEVELOPMENT AND PHILOSOPHICAL FOUNDATIONS OF THE DISCIPLINE (BASED ON THE REFORMS OF THE TANG DYNASTY)

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СТАНОВЛЕНИЕ ПОЛИТИЧЕСКОЙ НАУКИ: ИСТОРИЧЕСКОЕ ФОРМИРОВАНИЕ И ФИЛОСОФСКИЕ ОСНОВАНИЯ ДИСЦИПЛИНЫ (НА ПРИМЕРЕ РЕФОРМ ДИНАСТИИ ТАН)

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Abstract

This article examines the historical formation and philosophical foundations of political science as an academic discipline, with a particular focus on the administrative reforms of the Tang Dynasty (618–907 CE) as a non-European case study. The study traces the evolution of political thought from antiquity and the Middle Ages through the Enlightenment, analysing how philosophical paradigms — including Platonic normativism, Aristotelian empiricism, Confucian political ethics, and Weberian rationalism — shaped the methodological identity of political science. The Tang Dynasty is presented not merely as a historical example but as a substantive model of ontological and epistemological foundations of political knowledge: the Mandate of Heaven (tian ming) as a theory of legitimate authority, the Tang Code (Tanglü Shuyi) as a codified normative-analytical framework, and the imperial examination system (keju) as an institutionalised meritocracy. Through a comparative analysis of European institutionalisation of political science in the 19th–20th centuries and Tang administrative structures, the article identifies universal principles underlying effective governance: centralisation with functional specialisation, procedural standardisation, meritocratic recruitment, and synthesis of moral legitimacy with rational-legal authority. The findings suggest that political science as a discipline is inherently intercultural, and that non-Western historical experiences — particularly those of the Tang Dynasty — offer methodologically valuable insights for contemporary comparative politics, institutional theory, and the study of bureaucratic design.

Аннотация

В данной статье рассматриваются историческое становление и философские основы политологии как академической дисциплины, с особым акцентом на административных реформах династии Тан (618–907 гг. н.э.) как на неевропейском примере. Исследование прослеживает эволюцию политической мысли от античности и Средневековья до эпохи Просвещения, анализируя, как философские парадигмы — включая платоновский нормативность, аристотелевский эмпиризм, конфуцианскую политическую этику и веберовский рационализм — формировали методологическую идентичность политологии. Династия Тан пред-

ставлена не просто как исторический пример, но как содержательная модель онтологических и эпистемологических основ политического знания: Мандат Небес (тяньмин) как теория легитимной власти, Кодекс Тан (танлю шуи) как кодифицированная нормативно-аналитическая структура и императорская экзаменационная система (кецзю) как институционализированная меритократия. На основе сравнительного анализа европейской институционализации политологии в XIX–XX веках и административных структур династии Тан в статье определены универсальные принципы, лежащие в основе эффективного управления: централизация с функциональной специализацией, стандартизация процедур, меритократический подход к найму и синтез моральной легитимности с рационально-правовой властью. Результаты показывают, что политология как дисциплина по своей природе является межкультурной, и что незападный исторический опыт — особенно опыт династии Тан — предлагает методологически ценные идеи для современной сравнительной политологии, институциональной теории и изучения бюрократического устройства.

Keywords: political science, philosophy of science, Tang Dynasty, institutionalisation, Confucianism, bureaucracy, meritocracy, legitimacy, ontology, epistemology, comparative politics, administrative reform, Mandate of Heaven, Tang Code, keju examination system.

Ключевые слова: политология, философия науки, династия Тан, институционализация, конфуцианство, бюрократия, меритократия, легитимность, онтология, эпистемология, сравнительная политология, административная реформа, Мандат Небес, кодекс Тан, система экзаменов кецзю.

Введение

Политология как самостоятельная академическая дисциплина возникла на пересечении философии, истории, права и социологии, пройдя долгий путь от древних размышлений о полисе и справедливом государстве до современных эмпирических и интерпретативных моделей анализа власти. В отличие от естественных наук, её развитие не было линейным: политическое знание эволюционировало как пространство идей, в котором философские концепции человека, общества и власти определяли способы научного понимания политической реальности.

Особое значение этого процесса усиливается в контексте современных глобальных трансформаций — цифровизации политики, растущих символических и информационных измерений власти и сдвига мировой системы в сторону полицентризма. В этих условиях возвращение к истории политологии и её философским основам позволяет понимать дисциплину не как совокупность разрозненных теорий, а как результат изменения научных парадигм и типов рациональности. Именно философия науки предоставляет инструменты для реконструкции этой эволюции, позволяя рассматривать политологию как диалог между нормативным и эмпирическим подходами, ценностными ориентациями и аналитическими моделями [1].

Восточные политические традиции также имеют важное значение. В данной статье аналитический анализ сосредоточен на реформах династии Тан (618–907 гг. н.э.), в ходе которых систематически развивались принципы рационального управления, институционализация бюрократии и легитимность власти. Эти исторические преобразования демонстрируют, что формирование эффективных государственных институтов и систематизация политических знаний носили универсальный характер, представляя собой важный этап в эволюции политической мысли за пределами европейского контекста [2].

Актуальность данного исследования обусловлена кризисом традиционных теоретических парадигм политологии на фоне трансформации глобаль-

ной политической системы. Современная политическая реальность характеризуется эрозией классических моделей суверенитета, возрастающей ролью негосударственных акторов, усилением медийной реальности и символической политики. В этой ситуации универсальность устоявшихся объяснительных схем, сформированных в рамках западных позитивистских и бихевиористских традиций, все чаще ставится под сомнение [3].

Цель данной статьи — выявить отличительные черты исторического формирования политологии и проанализировать её философские основы в контексте методологических вызовов, стоящих перед современной дисциплиной, опираясь на административные реформы династии Тан.

Степень изученности темы исследования

Проблема формирования политической науки и её философских основ изучалась на разных этапах социально-гуманитарного знания в рамках различных научных традиций. Фундаментальный вклад в понимание политического знания внесли работы классиков политической и социальной мысли XIX и начала XX веков. Работы Карла Маркса (1840-е – 1870-е годы) заложили основу для структурного и материального понимания политики как производной социальных отношений [4]. Исследования Макса Вебера, проводившиеся в Германии в начале XX века (1904–1920), сыграли центральную роль в формировании научного подхода к анализу власти, легитимности и бюрократии, а также в разграничении нормативного и эмпирического знания [5].

Философско-методологические размышления о политической науке развивались в рамках философии науки середины XX века: Карл Поппер установил принципы научной рациональности и фальсификации, а Томас Кун предложил концепцию научных парадигм, применимых к анализу эволюции политической науки [6]. В политической теории второй половины XX века нормативно-философское направление занимало значительное место (Лео Штраус, Джон Ролз).

В постсоветский период (1990-е – 2010-е годы) вопросы институционализации и методологии политологии активно исследовались в России, Казахстане и других странах Центральной Азии. Особый

интерес представляют работы, посвященные адаптации западных теоретических моделей к историческим и культурным реалиям региона. Изучение восточных политических традиций в западной академической литературе остается относительно ограниченным. Авторитетные работы по китайской политической мысли, в том числе работы Джона-тана Спенса [7] и сравнительных институционалистов, признают значимость административной системы династии Тан как исторически предшествующей модели рационального управления. Однако всесторонний философский и научный анализ формирования политологии, учитывающий восточный опыт, в частности реформы династии Тан как пример институционализации политического знания и рационального управления, остается недостаточно представленным в существующей литературе.

Данная статья призвана восполнить этот пробел, рассматривая реформы династии Тан в более широком контексте истории политологии, анализируя их не просто как историческую диковинку, а как содержательное исследование для понимания философских и методологических основ дисциплины. Интеграция восточной и западной перспектив таким образом способствует более полному и подлинно сравнительному анализу того, как политология как форма систематического знания о государственной власти развивалась в различных цивилизационных контекстах.

Методология и материалы исследования

В данной статье используется многометодовый качественный подход, сочетающий историко-философский анализ, сравнительную методологию и систематический обзор первичных и вторичных источников. Историко-философский метод применяется для прослеживания эволюции политической мысли от античности через эпоху Просвещения и до XX века, исследуя концептуальный вклад ведущих мыслителей в формирование политической науки. Сравнительный метод используется для сопоставления европейской институционализации политической науки в XIX–XX веках с административными и институциональными реформами династии Тан, выявляя сходства и расхождения в логике формирования политического знания.

Первичные источники включают классические политические тексты: «Политика» Аристотеля, «Республика» Платона, «Государь» Макиавелли, «О республике» Цицерона, а также основополагающие документы династии Тан, в частности, Кодекс Тан с комментариями (Танлю Шуи, 653 г. н.э.). В качестве вторичных источников используется научная литература по политической теории, философии науки, истории Китая и сравнительной политологии, включая работы Макса Вебера, Карла Поппера, Томаса Куна, Эндрю Хейвуда и современных историков периода Тан. Интерпретативный метод применяется для анализа философских категорий — онтологии, эпистемологии, легитимности и рациональности — в том виде, в котором они проявляются как в западных теоретических традициях, так и в практике управления династии Тан.

Основная часть

Политическая мысль античности и Средневековья как предыстория политической науки. Формирование политической науки как самостоятельной дисциплины невозможно рассматривать вне контекста античной и средневековой политической мысли, поскольку именно в эти эпохи были заложены основополагающие концепции власти, государства и взаимодействия правителя и общества. Античная политическая мысль формировалась на пересечении философии, этики, права и практической политики. В работах Платона, в частности в «Республике» и «Законах», формулируются нормативные модели идеального полиса, основанные на гармонии социальных слоев, справедливом распределении ролей и обязанностей, а также роли разума в управлении. Платон подчеркивал, что правитель должен обладать не только властью, но и мудростью, закладывая основу для идеи квалифицированного бюрократического управления — концепции, имеющей фундаментальное значение для анализа реформ династии Тан [8].

Аристотель в «Политике» развивает аналитический и эмпирический подход к изучению форм правления, классифицируя их на правильные формы (монархия, аристократия, политическое устройство) и отклоняющиеся формы (тирания, олигархия, демократия). Он подчеркивает важность изучения реальных практик управления, а не только идеальных моделей — важнейший элемент методологической основы политической науки. Аристотель также рассматривал государство как органическую систему, в которой каждый элемент выполняет свою функцию, аналогично поздней бюрократической структуре династии Тан, где от чиновников и институтов ожидалось скоординированное действие для поддержания стабильности государства [9].

Римская политическая традиция, представленная в работах Цицерона, усиливает правовое измерение политической мысли. Цицерон рассматривает легитимность власти через призму права и обязанностей граждан, формируя идею законности как основу для анализа власти. Римская система права и управления оказала долгосрочное влияние на европейскую политическую науку, а также на восточные административные традиции, включая практику династии Тан, где законы и правила строго регулировали деятельность чиновников [10].

Средневековая политическая мысль, сформированная христианской теологией, сохранила и развила эти концепции, переосмыслив их в морально-религиозной парадигме. Августин Гиппонский в «О граде Божьем» рассматривает земное государство как инструмент поддержания порядка в грешном мире, демонстрируя ранний синтез философии, религии и политики. Синтез Фомой Аквинским аристотелевской философии и христианской теологии заложил основу для светских моделей государства, которые впоследствии развились в современную эпоху, учитывая восточные традиции управления, включая китайскую бюрократическую практику династии Тан [11].

Особое значение древних и средневековых концепций для восточной традиции заключается в формировании ими универсальных категорий для понимания власти, права и ответственности. В Китае философские идеи Конфуция и легистов гармонично сочетались с практикой государственного управления, что проявилось в систематизации бюрократии и законодательных реформах династии Тан. Анализ этих процессов показывает, что античные и средневековые модели обеспечивают методологическую основу для изучения политологии как дисциплины, способной синтезировать философские основы и практические механизмы государственного управления.

Формирование политической науки в современную эпоху и эпоху Просвещения в контексте восточной традиции. Современная эпоха и эпоха Просвещения характеризуются переходом от теологических и нормативно-философских моделей государства к более рациональным и эмпирически ориентированным подходам. В этот период политическая мысль становилась все более систематизированной, и были заложены основополагающие принципы суверенитета, прав человека и участия народа в управлении. Труды Никколо Макиавелли, в частности «Государь», заложили основы политической рациональности — наряду с моральными и идеальными концепциями, первостепенное значение приобрели эффективность управления, стабильность власти и стратегическое поведение правителя. Эти идеи значительно перекликаются с бюрократической системой династии Тан, в которой император и чиновники действовали прагматично, опираясь на четко формализованные законы и правила и стремясь к гармонии между централизованной властью и местными институтами управления [12].

Философы эпохи Просвещения, включая Джона Локка и Жан-Жака Руссо, разработали концепции народного суверенитета, общественного договора и легитимности власти. Локк подчеркивал необходимость защиты естественных прав личности и ограничения произвола власти, заложив основу для демократических моделей управления, в то время как Руссо сформулировал идею общественного договора как механизма примирения индивидуальных и коллективных интересов. Эти европейские идеи находят параллели в китайской политической практике: реформы династии Тан были направлены на укрепление морального и юридического авторитета императора, который можно рассматривать как аналог легитимной власти в европейской политической мысли, а также как инструмент поддержания общественного порядка и справедливости [13].

Особого внимания заслуживает методологическая интеграция философии и практики. В отличие от античных теоретиков, мыслители современной эпохи заложили основы политической науки как дисциплины, в которой идеи проверяются посредством эмпирического наблюдения, анализа исторических примеров и практики управления. Например, Хуго Гроций и Бенджамин Констан разработали идеи естественного права и рациональной

организации государства, которые стали аналитическими инструментами для оценки эффективности политических институтов. Подобные подходы нашли отражение в бюрократических реформах династии Тан, где стандартизация ведомств, система экзаменов и регламентированные процедуры обеспечили эффективность государственного аппарата и взаимодействие центральной и местной власти.

Эпоха Просвещения также усилила внимание к социально-экономическим аспектам управления. Такие мыслители, как Адам Смит и Монтескье, исследовали влияние законодательства, экономических структур и разделения властей на стабильность государства. Эти принципы находят отражение в восточной традиции, где династия Тан провела всеобъемлющие административные и налоговые реформы, регулирующие экономическую деятельность и распределение ресурсов, тем самым обеспечив стабильность государственной системы и легитимность управления [14].

Таким образом, современная эпоха и Просвещение заложили методологические основы политической науки, сочетая нормативные идеи с эмпирическим исследованием. Сравнение европейских концепций с практикой династии Тан выявляет универсальные закономерности в формировании политического знания: рациональность, легитимность власти, структурированная бюрократия, внимание к экономическим и социальным факторам, а также прочная связь между философскими основами и практическими институтами управления. Это демонстрирует, что формирование политической науки является межкультурным процессом, интегрирующим западные и восточные традиции анализа государства и власти.

Институционализация политологии: сравнительный анализ европейской практики и реформ династии Тан. Институционализация политологии как самостоятельной дисциплины в Европе началась в XIX–XX веках и была связана с развитием академической инфраструктуры: созданием специализированных учебных заведений, кафедр политологии и научных журналов, посвященных изучению политики, государства и международных отношений. В этот период были установлены профессиональные стандарты политического анализа, охватывающие классификацию форм правления, методы сравнительного изучения государственных систем, систематизацию теоретических подходов и эмпирическую проверку гипотез [15].

Параллельно, в период династии Тан (618–907 гг. н.э.) Китай пережил всеобъемлющую институциональную реформу, направленную на централизацию власти и повышение эффективности управления. Были разработаны стандартизированные бюрократические структуры с четкой иерархией должностных лиц; введена система экзаменов для отбора государственных служащих; урегулированы процедуры назначения и отчетности; Были разработаны единые административно-правовые кодексы. Эти меры обеспечили стабильность управления, контроль над ресурсами и приверженность принципам рациональной власти, что по сути

стало практическим воплощением идеи легитимности и эффективности государственного аппарата.

Сравнительный анализ европейской и китайской практики показывает, что институционализация политической науки носит универсальный характер, независимо от культурного и исторического контекста. В Европе формирование политической науки опиралось на развитие научной бюрократии, статистики, юриспруденции и социологии, что позволило создать методологическую основу для систематического изучения государства. В Китае реформы Тан демонстрируют, что практический опыт эффективного государственного управления может служить основой для методологического понимания политических институтов: стандартизация ведомств, регулирование административных процедур и разработка кодифицированных правил позволили прогнозировать поведение чиновников, оценивать эффективность решений и поддерживать стабильность политической системы.

Особое значение имеет межкультурный анализ. Сопоставление европейских и китайских моделей показывает, что институционализация политологии — это не только создание академических структур, но и формирование систематического подхода к изучению государства и власти. Реформы династии Тан демонстрируют, как философские, правовые и административные элементы могут быть интегрированы в целостную систему анализа, в которой теория и практика дополняют друг друга. Этот опыт подчеркивает, что эффективная политология предполагает связь между методологическим осмыслением и институциональной практикой, что позволяет выявлять закономерности управления, сохраняющие свою актуальность для современных исследований.

Онтологические и эпистемологические основы политической науки в контексте реформ династии Тан. Онтологические и эпистемологические основы политической науки определяют сущность государства как социального организма, природу власти и методы её познания. В династии Тан (618–907 гг. н.э.) эти основы воплотились в комплексных реформах, которые гармонизировали конфуцианскую философию с административной практикой, укрепили легитимность имперской власти и обеспечили систематизацию управления посредством синтеза космологии, морали и прагматизма.

Конфуцианство, доминировавшее в период Тан, онтологически интерпретировало государство как «Великое Единство» (да цзун) — органическое целое, отражающее небесный порядок. Правитель — «Сын Неба» (тяньцзы) — воплощал Мандат Неба (тяньмин), который напрямую зависел от добродетели (дэ) и соблюдения ритуалов (ли). Император Тайцзун (626–649 гг. н.э.) в своих административных инициативах, отраженных в «Кодексе Тан с комментариями» (Танлю Шуй), подчеркивал, что власть — это не привилегия, а ответственность за гармонию неба, земли и людей, выраженная через Пять Постоянных Взаимоотношений (у лунь): правитель-подданный, отец-сын, супруги, старший-

младший и друзья. Такой подход позволил стабилизировать государство после кризиса династии Суй, где потеря «Мандата Небес» привела к катастрофическим последствиям [16].

Императрица У Цзэтянь (690–705 гг. н.э.) адаптировала онтологию власти, введя буддийско-даосские элементы (культ Майтрейи), расширив конфуцианскую гармонию до всеобъемлющей космологии инь-ян. Это легитимизировало женское правление как принцип равновесия, демонстрируя способность политической системы к самоадаптации и включению различных философских школ. Государство рассматривалось как телос — цель саморегулирующегося организма — аналогично «Республике» Платона, где каждая часть выполняет свою функцию на благо целого.

Сравнительный анализ показывает универсальность этой онтологии: Гоббс на Западе представлял государство как «Левиафана», защищающего от анархии, что контрастирует с танским представлением о гармонии; однако это перекликается с руссоистской концепцией власти, служащей общему благу. Аристотелевский взгляд на полис как на естественную форму социальной организации перекликается с идеей дацзун, подчеркивая телеологическое значение власти и ее роль в поддержании целостности государства [17].

Эпистемология политической науки в период династии Тан основывалась на систематизации знаний о государстве посредством нормативных и эмпирических инструментов. Кодекс Тан (Танлю Шуй, 653 г. н.э., Тайцзун) объединил конфуцианские принципы (ли) с юридической логикой легизма (фа), создав аналитическую основу для познания политической реальности. Кодекс регулировал более 500 статей, классифицировал правонарушения, определял права и обязанности должностных лиц и подданных, а также обеспечивал методологическую предсказуемость и унификацию процедур.

Система экзаменов (кецзю), реформированная при императоре Сюаньцзуне (712–756 гг. н.э.), ввела объективные критерии отбора должностных лиц на основе конфуцианских текстов (шицзин, чжуанцзы), минимизируя влияние аристократических кланов (сидафу). Примерно к 800 г. н.э. около 70% должностных лиц отбирались меритократическим путем, что обеспечивало административную компетентность и предсказуемость действий администрации. Таким образом, знания о государстве и управлении стали эмпирически проверяемыми и стандартизированными [18].

Эта практика аналогична западной рационализации власти: Локк и Монтескье сформировали эпистемологию посредством эмпирического наблюдения и принципов разделения властей; Танцы интегрировали теорию с практикой управления, создав систематическую основу для анализа, оценки и прогнозирования государственных процессов. Этот синтез онтологии и эпистемологии породил стабильные институциональные структуры, в которых моральное и рациональное управление дополняли друг друга.

Методологические подходы и практическое значение институциональных и административных моделей династии Тан. Реформы династии Тан представляют собой уникальный исторический пример того, как институциональная рациональность может быть тесно интегрирована с философской легитимацией власти и практической организацией государства. Методологически они демонстрируют, что политическая система может одновременно быть объектом управления и предметом систематического анализа, тем самым закладывая прочную основу для институционального изучения власти.

Центральная бюрократическая структура династии Тан характеризовалась высокой степенью специализации и вертикальной подотчетностью. Центральный секретариат (Чжуншу шэн) координировал принятие ключевых государственных решений, в то время как Шесть министерств (Шаншу шэн) разделяли функции по областям: финансы (Ху бу), военные дела (Бин бу), образование и ритуалы (Ли бу), судебные дела (Син бу), инфраструктура (Гун бу) и кадровая политика (Ли бу). Эта система позволяла поддерживать баланс между централизацией и делегированием полномочий: решения принимались централизованно, но исполнение и надзор были возложены на специализированные органы, что обеспечивало согласованность действий и предсказуемость управления [19].

Иерархия чиновников также была четко структурирована. Император Тайцзун ввел классификацию должностей (цзю пин), в то время как местные губернаторы (циси) отчитывались перед инспекторами (юси). Одновременно реформы экзаменационной системы (кэцзю) позволили отбирать компетентных чиновников на основе знания конфуцианских текстов, минимизируя влияние аристократических семей (сидафу) и способствуя формированию меритократии. К VIII веку примерно 70% административного корпуса состояло из лиц, прошедших отборочный экзамен, что обеспечивало не только квалификацию персонала, но и предсказуемость и стабильность работы государственных учреждений [20].

Особое значение имела интеграция философских принципов с практическими процедурами. Конфуцианские идеалы (ли) стали основой норм и стандартов бюрократической этики, а кодифицированные законы и механизмы инспекции служили инструментами оценки и контроля деятельности чиновников. Этот синтез позволил поддерживать гармонию между моральными целями управления и рациональной эффективностью институтов. Опыт восстания Ань Лушаня (755 г. н.э.) показывает, что даже в критические периоды стабильная бюрократическая структура позволяла государству адаптироваться и восстанавливаться, сохраняя централизованное руководство и контроль над ресурсами [21].

С точки зрения политологии, опыт династии Тан демонстрирует универсальные принципы институционального проектирования: централизация и координация власти через Центральный секретариат; делегирование и специализация функций

внутри министерств; меритократия и стандартизация процедур, обеспечивающие компетентность чиновников; системный и адаптивный характер институтов, позволяющий государству устойчиво реагировать на кризисы; и синтез идеологии и практики, где моральные принципы интегрированы в повседневное функционирование бюрократии.

В сравнении с западной традицией, административный опыт династии Тан соотносится с концепцией рационально-правовой власти Вебера, в которой закон и процедуры вытесняют личную харизму, а также предвосхищает идеи институциональной зависимости от предшествующего развития (Пирсон, 2004), демонстрируя, как инерция и структурная организация бюрократии создают стабильность политической системы.

Таким образом, административно-институциональная модель династии Тан является не только примером эффективного государственного управления, но и методологически ценным примером для политологии. Она демонстрирует, как сочетание онтологической гармонии власти и эпистемологической систематизации знаний и процедур создает стабильные и адаптивные политические институты, предлагая современные уроки для сравнительной политологии, анализа легитимности власти и моделирования бюрократических процессов.

Заключение

Анализ реформ династии Тан показывает, что исторический опыт Китая VIII века представляет собой уникальный пример синтеза философской легитимации власти, институциональной рациональности и практической организации государства. Централизованная бюрократическая структура, делегирование полномочий через шесть министерств и система экзаменов «кецзю» сформировали стабильный административный аппарат, способный адаптироваться к кризисам, обеспечивать контроль над ресурсами и поддерживать согласованность действий на всех уровнях управления. Реформы Тайцзуна и Сюаньцзуна демонстрируют, что эффективность государства напрямую связана с компетентностью и подотчетностью чиновников, и что моральные и идеологические принципы (ли), интегрированные в повседневное управление, укрепляют легитимность власти и стабильность системы.

С точки зрения политологии, опыт династии Тан иллюстрирует универсальные методологические принципы: систематичность, стандартизация процедур, меритократический отбор, синтез морального и рационального в управлении и путь адаптации институтов к внутренним и внешним вызовам. Эти принципы нашли отражение в современных теориях институционального проектирования, сравнительной политологии и изучении бюрократических структур, включая концепции Вебера о рационально-правовой власти и анализ институциональной зависимости от предшествующего развития. Таким образом, изучение династии Тан позволяет увидеть, как исторические модели государственного управления становятся источником методологического понимания власти, механизмом

прогнозирования политических процессов и инструментом сравнительного анализа между Востоком и Западом.

Особое значение приобретает междисциплинарная перспектива: синтез философских, правовых и административных подходов формирует методологическую основу, на которой строится современная политология как академическая дисциплина. Опыт династии Тан демонстрирует, что исторические реформы не только решали практические задачи управления, но и создавали стандарты для систематизации политических знаний, обеспечивающие долгосрочную стабильность институтов. В этом контексте реформы Тан становятся ценным примером для анализа легитимности власти, эффективности бюрократии и культурно адаптированных моделей государственного управления.

Результаты исследования имеют более широкие последствия для историографии политологии. Распространенная тенденция проследить интеллектуальную генеалогию дисциплины исключительно через западную мысль — от Платона и Аристотеля до Макиавелли, Вебера и далее — рискует привести к частичному и этноцентричному описанию того, как человеческие общества теоретизировали и институционализировали политическое знание. Случай с династией Тан демонстрирует, что систематическое осмысление государственного управления, кодификация административных норм и рациональный отбор государственных служащих — все это отличительные черты того, что мы ассоциируем с научным изучением политики — существовало за столетия до формального появления политологии как западной академической дисциплины. Поэтому включение таких незападных случаев в историю политологии — это не просто жест инклюзивности, а методологическая необходимость для дисциплины, которая стремится к подлинно сравнительным и универсальным утверждениям.

Дальнейшие исследования могут продуктивно расширить эту сравнительную концепцию на другие династические периоды китайской истории, на османскую административную традицию или на структуры управления доколониальных государств Центральной Азии, что еще больше обогатит философские и методологические основы политологии как глобальной дисциплины.

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PSYCHOLOGICAL SCIENCES

INVESTIGATION OF VULNERABLE NARCISSISM LEVELS OF UNIVERSITY STUDENTS ACCORDING TO DEMOGRAPHIC VARIABLES

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ÜNİVERSİTE ÖĞRENCİLERİNİN KIRILGAN NARSİSİZM DÜZEYLERİNİN DEMOGRAFİK DEĞİŞKENLERE GÖRE İNCELENMESİ

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Abstract

The aim of this research is to examine the levels of fragile narcissism among university students according to demographic variables. Fragile narcissism has been associated with sensitivity to criticism, depressive thoughts, excessively humble attitudes, and grandiose expectations in relationships. The Fragile Narcissism Scale (VNS) and a personal information form were used to collect data. The prepared forms and scale data were sent to participants online via Google Forms. A total of 240 university students aged 18 and over (120 women and 120 men) studying in the 2025-2026 academic year participated in the study. After conducting a normality test on the data, it was determined that the data showed a normal distribution; accordingly, the parametric test methods "Independent Groups t-Test" and "One-Way Analysis of Variance (ANOVA)" were used. The results of the data analysis revealed that students' fragile narcissism scores showed a significant difference according to the gender variable. When considering the class level variable, no statistically significant difference was found between the groups; A statistically significant difference was observed in the levels of fragile narcissism in relation to the economic level variable. The results obtained from this research were discussed in light of previous studies, and suggestions were offered to contribute to the literature in this context.

Özet

Bu araştırmanın amacı üniversite öğrencilerinin kırılğan narsisizm düzeylerinin demografik değişkenlere göre incelenmesidir. Kırılğan narsisizm eleştiriye hassasiyet, depresif düşünceler, aşırıya kaçan alçak gönüllü tutumlar ve ilişkilerde büyülenmeci beklentiler içerisinde olmakla ilişkilendirilmiştir. Araştırmada veri toplamak amacıyla Kırılğan Narsisizm Ölçeği (KNÖ) ve kişisel bilgi formu kullanılmıştır. Verileri elde etmek için hazırlanan form ve ölçek verileri google formlar üzerinden online şekilde katılımcılara iletilmiştir. Araştırmaya 2025-2026 yılında eğitim gören 120 kadın 120 erkek olmak üzere 18 yaş ve üzeri toplam 240 üniversite öğrencisi katılım sağlamıştır. Verilerin normallik dağılım testi yapıldıktan sonra normal dağılım gösterdiği belirlenmiş bu doğrultuda parametrik test yöntemlerinden "Bağımsız Gruplar t-Testi" ve "Tek Yönlü Varyans Analizi (ANOVA)" kullanılmıştır. Verilerin analizi sonucunda bulgular öğrencilerin kırılğan narsisizm puanlarının cinsiyet değişkenine göre anlamlı bir farklılık gösterdiğini belirlemiştir. Sınıf düzeyi değişkenine bakıldığında gruplar arasında istatistiksel olarak anlamlı bir fark bulunmamış; ekonomik düzey değişkeninde ise kırılğan narsisizm düzeyleri üzerinde istatistiksel olarak anlamlı bir fark görülmüştür. Bu araştırmadan elde edilen sonuçlar, yapılan çalışmalar ışığında tartışılmış ve konuya yönelik öneriler sunularak araştırmanın bu kapsamda literatüre katkı sağlaması amaçlanmıştır.

Keywords : Narcissism, grandiose narcissism, vulnerable narcissism, demographic variables

Anahtar Kelimeler: Narsisizm, büyülenmeci narsisizm, kırılğan narsisizm, demografik değişkenler

1. GİRİŞ

Üniversite yılları bireylerin ergenlikten genç yetişkinlik dönemine adım attığı bir geçiş dönemidir ve bu iki dönem arasındaki bir köprüye benzetilebilir. Bu dönemde bireyler bir çatışma dönemi olan ergenlikten henüz çıkmıştır ve girmiş oldukları yeni ortama, sosyal roller ve ilişkilere uyum sağlama aşamasındadırlar.

Yine bu dönemdeki bireyler ortama uyum sağlamakla birlikte akademik başarı, sorumluluk alma, mesleki bilgi ve beceriler ile sosyal çevre edinme süreci içerisinde olmaktadır [1]. Narsisizm kavramı son yıllarda günlük dilde de sıkça kullanılan ve gündemde olan bir kavram olarak karşımıza çıkmaktadır. Narsisizm; kişinin sosyal ilişkilerini, benliğine yönelik bakış açısını

psikolojik ve ruhsal iyi oluş düzeyini büyük ölçüde etkileyen, çok faktörlü bir kavram olarak tanımlanmıştır [2, s.2]. Narsisizm kavramı, kökenini Yunan mitolojisinde sudaki yansımaya aşık olan ve bu imkansız aşkın peşinde ömrünü tüketen Narkissos efsanesinden almaktadır. Kavramın psikoloji literatüründeki ilk izleri, 1898 yılında Ellis'in bu durumu kişinin kendi vücuduna yönelttiği hayranlık olarak tanımlamasıyla görülmüştür [3, s.48]. Psikanalitik kuramın kurucusu Sigmund Freud ise narsisizmi, dış dünyadan çekilen libidonun benliğe yöneltilmesi durumu olarak açıklayarak konuyu bilimsel bir zemine oturtmuştur [4, s.16]. Freud narsisizmi belirli bir gelişimsel evre olarak ele alırken, Jung ve onu takip eden araştırmacılar bu olguyu yaşam boyu süregelen bir dinamik olarak görmüşlerdir [3, s.50]. Bireyin gelişimsel sürecine bakıldığında, narsistik eğilimlerin yaşamın ilk aylarındaki yalnızlık duygusu ve temel ihtiyaçların karşılanmaması sonucu oluşan hayal kırıklıklarıyla şekillendiği bildirilmektedir [5, s.4]. Sağlıklı bir gelişim için bakım veren kişiyle kurulması gereken aynalama ve idealizasyon bağının oluşmaması, bireyin dış dünya yerine kendi iç dünyasına yatırım yapmasına neden olmaktadır [6]. Literatürde narsisizm, normal ve patolojik olmak üzere iki temel boyutta ele alınmaktadır [3, s.49]. Normal narsisizm; bireyin özgüveninin sağlıklı bir düzeyde olması, kendisiyle barışık yaşaması ve çevreden gelen yapıcı eleştirileri benlik saygısını yitirmeden kabul edebilmesidir [7, s.28]. Her bireyin temelde sevilme, beğenilme ve onaylanma gibi narsistik gereksinimleri mevcuttur ve bu ihtiyaçların dengeli şekilde doyurulması psikolojik sağlık için gereklidir [3, s.51]. Patolojik narsisizm ise, dışarıdan bakıldığında aşırı bir özgüven ve görkemli bir kendilik sunumu gibi görünse de, aslında bireyin benliğini ayakta tutabilmek için başkalarının hayranlığına muhtaçlık duymasındır. Patolojik narsisizmde ego ve süperegonun bütünleşme eksikliği yaşar ve bu durum çocukluktaki kusurlu nesne ilişkilerinden kaynaklanır [8]. Grandiyöz (görkemli) bir tarzda önemli olma duygusu, empati yoksunluğu, sınırsız başarı düşlemleri ve sürekli bir başarı beklentisiyle karakterize olan bu kavram "Narsistik Kişilik Bozukluğu" (NKB) adıyla resmi bir tanı alması 1980 yılında yayımlanan DSM-III ile birlikte olmuştur [5, s.6]. Narsistik bireyler bekledikleri onayı dışarıdan alamadıklarında derin bir anlamsızlık ve boşluğa düşüp depresyon yaşayabilirler. Bu boşluğu kapatmak için de kendilerini üstün hissettirecek statü ve nesnelere aşırı yatırım yapabilirler [6]. Güncel literatürde narsisizm küstah ve sergileyici tutumlarla ifade edilen "açık narsisizm" ve daha kapalı, savunmacı özelliklerle ilişkilendirilmiş "kapalı narsisizm" olarak da kategorilenmiştir. Narsisizmin değerlendirilmesinde yaygın olarak kullanılan hem projektif hem de objektif testler bulunmaktadır [3, s.51]. Nicel araştırmalarda Raskin ve Hall tarafından geliştirilen Narsistik Kişilik Envanteri (NPI), Rorschach Testi gibi projektif yöntemler ise bilinçdışı süreç ve kişilik dinamiklerini anlamak için tercih edilmektedir [9, s.7]. Araştırmalar narsisizmin yaş, cinsiyet gibi değişkenlerle her zaman için doğrudan ilişkisi olmasa da narsistik özelliklerin engellenme durumunda saldırganlık ve öfke patlamalarıyla ilişkili olabileceğini göstermiştir [10]. Literatürde son

yıllarda narsisizmin sosyal ve iş yaşamındaki etkilerine değinilmekle birlikte narsistik bireylerin yüksek motivasyon ve karakteristik duruşlarıyla liderlik rolünde avantajlı olabilirken empati yoksunlukları ekip içi çatışmalara neden olabilmektedir [11]. Ayrıca teknolojinin ilerlemesiyle birlikte, narsistik "hak iddia etme" ve "üstünlük" özelliklerinin internet bağımlılığı ve siber zorbalık ile ilişki içerisinde olduğu bulgulanmıştır [12]. Tüm bu veriler ışığında narsisizm, bireyin erken çocukluk yaşantılarından mesleki başarısına kadar geniş bir yelpazeyi etkileyen karmaşık bir kişilik örüntüsü olarak önemli bir kavram haline gelmektedir. Bu kapsamda üniversite çağındaki öğrenciler için narsisizm kavramı içinde bulundukları dönemin özellikleri açısından kritik bir öneme sahip olabilir. Narsisizm kavramının anlaşılması ve özellikle içe dönüklük, eleştiriye karşı aşırı hassaslık, aşırı alçakgönüllülük ilişkilerde büyülenmeci tutumlar gibi özelliklerle ilişkili olan kırılan narsisizm boyutunun anlaşılması üniversite dönemi bireyleri anlamak için önemli olabilmektedir.

Araştırmanın Amacı

Bu araştırmanın amacı üniversite düzeyindeki öğrencilerin kırılan narsisizm düzeylerinin demografik değişkenlerle ilişkisini ortaya koymaktır. Bu kapsamda araştırmanın alt amaçları şu şekilde belirlenmiştir:

1. Üniversite öğrencilerinin kırılan narsisizm puanları cinsiyet değişkenine göre istatistiksel olarak anlamlı bir farklılık göstermekte midir?
2. Öğrencilerin sınıf düzeyi yükseldikçe, kırılan narsisizm düzeyleri istatistiksel olarak anlamlı bir farklılık göstermekte midir?
3. Algılanan ekonomik düzey ile kırılan narsisizm puanları arasında istatistiksel olarak anlamlı bir ilişki bulunmakta mıdır?

2. LİTERATÜR

Narsisizm, bir yandan normal gelişimin bir parçası olmakla birlikte öte yandan kişilik özellikleri açısından bakıldığında patolojik boyutu olan, geniş bir alana yayılmış karmaşık bir olgudur. Tarihsel süreçler incelendiğinde mitolojik temellerden doğarak zamanla klinik bir tanı sürecine geçtiğini söylenebilir.. Yunan mitolojisinde değinilen sudaki yansımaları görüp kendi yansımaya aşık olarak aşırı hayranlık duyan Narkissos karakteri narsisizm olgusunun mitolojik temelini oluşturur [13, s.130]. Günümüze bakıldığında kişilerin öz-saygı düzenlemesindeki anormallikleri yansıtan bir metafor halini aldığı görülmektedir. Kavramın literatürde bilimsel olarak ilk izleri, Havelock Ellis'in 1887 yılında bireyin cinsel dürtülerini kendi benliğine yöneltmesini anlatmak amacıyla "Narkissos benzeri" ifadesini kullanmasıyla ortaya çıkmıştır. Benliğin cinsel bir nesne olarak görüldüğü "oto-erotizm" kavramıyla ilişkilendirilen narsisizm; bireyin benliğine duyduğu hayranlık ile kendini büyük görme davranışlarıyla ilişkilendirilmiştir [14]. Freud, narsisizmi nesnelerden çekilen libidonun benliğe (egoya) yöneltilmesi şeklinde tanımlamış ve bunu "birincil narsisizm" olarak adlandırmıştır. Freud'a göre bu gelişimin doğal bir evresidir. "Narsisizm Üzerine Bir Giriş" adlı metninde Freud, bu egosantrik evrede bebeklerin dış dünyayı ayırt edemediği için libidonun benliğe yönetilmesinin patolojik değil, özgüven ve benlik

saygısı gelişimi için zorunlu bir başlangıç olduğunu vurgular. Fakat normal gelişim sürecinde enerjinin dış dünyaya yönelmesi gerekirken, çeşitli engellerle karşılaşp tekrar benliğe yönelmesi "ikincil narsisizm" olarak adlandırılır ve bu patolojik sürece zemin hazırlar [4]. Literatüre bakıldığında narsisizmin asıl klinik derinliğinin, Nesne İlişkileri ve Benlik Psikolojisi kuramsal tartışmalarında şekillendiği görülmektedir. Heinz Kohut, narsisizmi erken çocuklukta ebeveynlerin sunması gereken "aynalanma" ve "idealize edilme" gibi kendilik nesnesi ihtiyaçlarının giderilmemesi sonucunda ortaya çıkan gelişimsel bir duraklama şeklinde tanımlamıştır. Narsistik kişi, temelde kendilik bütünlüğünün eksikliğini tamamlamak için uğraşır [6]. Otto Kernberg ise narsisizmi daha patolojik bir çerçevede ele alarak bunun "ihtişamlı benlik" (grandiose self) denilen savunma yapısı olduğunu ileri sürmüş, temelde yatan sebebin ebeveynin çocuğun bazı yönlerine hayranlık duyması fakat çocuğa yine de duygusal açıdan soğuk ve reddedici tutumlar sergilemesinin olduğunu belirtmiştir [15]. Kernberg, bu yapıyı kişinin değersizlik, içsel boşluk ve haset duygularıyla baş etmek için geliştirdiği patolojik bir kalkana benzetir. Kuramsal açıyla narsisizm yalnız bir bozukluk olmayıp aynı zamanda "sağlıklı narsisizm" olarak kabul gören; kişilerin olumlu özsaygısının devamı, hırslarının peşinden koşması ve yaşamının uyum halini sürdürmesi için gerekli olan makul görülen bir kapasiteyi ifade eder [16, s.357]. Modern literatürde narsisizm; bir ucunda dışadönüklük, küstahlık ve düşük empati ile karakterize olan "büyükenmeci narsisizm" boyutunun olduğu diğer ucunda ise eleştiriye aşırı duyarlılık, düşük özgüven ve sosyal kaygı ile ilişkili "kırılgan narsisizm" boyutunun bulunduğu heterojen bir spektrum olarak kabul edilmektedir [17]. Narsisizmin klinik tanılama aşamasında Amerikan Psikiyatri Birliği [21] tarafından yayınlanan DSM-5 kriterleri esas alınmaktadır. DSM-5'in narsisizm belirtilerine bakıldığında; sınırsız başarı düşlemleri, aşırı beğenilme ihtiyacı, özel olduğuna inanma ve başkalarını sömürme eğiliminde olmak gibi dokuz maddeyi kapsayan bir belirti kümesi görülmektedir. Fakat güncel araştırmalar, DSM' daha çok büyükenmeci tip üzerinde durduğunu kırılgan narsisizm boyutunun ise daha geride kalabildiğini belirtmektedir [18]. Ayrıca narsisizm, kişilik psikolojisinde "Karanlık Üçlü" (Dark Triad) olarak bilinen; makyavelizm ve psikopati kavramları ile birlikte değerlendirilmektedir. Bu durumun etkilerinin hem iş yaşamındaki liderlik süreçlerinde hem de romantik ilişkilerde kritik olan sadakat ve bağlanma kalıplarını doğrudan etkilediği araştırmalarca vurgulanmıştır [19]. Narsisizm iki boyutu bulunmaktadır ilk boyut olan Büyükenmeci narsisizm, literatür de kişinin kendisini aşırı değerli görmesi, sömürücü eğilimler sergilemesi ve sosyal baskınlık kurma arzusuyla karakterize edilen çok boyutlu bir yapı olarak tanımlanmıştır [20]. Bu kişilik yapısına sahip bireyler en temelde "özel ve eşi bulunmaz biri" olduklarına dair bilişsel bir şemaya sahiptirler ve buna yönelik sarsılmaz bir inançları vardır [21]. Bu büyükenmeci kendilik algısı yalnız bir özgüven göstergesi olmayıp, aynı zamanda kişinin başarı ve yeteneklerini ölçüsüzce abarttığı patolojik bir durumdur [22] Büyükenmeci narsizm de kırılgan narsisizme göre düşük öz-saygı

veya derin bir yetersizlik duygusundan öte, yüksek am oldukça istikrarsız bir öz-saygı bulunur [18]. Beş faktör kişilik kuramı bakış açısıyla bu tip, genelde dışa dönüklük ile olumlu, nörotizm ile olumsuz bir ilişkiye sahiptir, bu durum onların neden daha dirençli ve özgüvenli bir görünüm sunduklarını açıklamaktadır. Kişilerarası ilişkiler boyutuna bakıldığında, büyükenmeci narsisizmin "soğuk ve sömürücü" bir doğaya sahip oldukları, sosyal çevrelerini empati kurmak veya duygusal yakınlık kurmak amacından ziyade, kendi statülerini yükseltmeye yönelik birer "hayran kitlesi" olarak kullanma eğilimi gösterirler [23]. Karanlık Üçlü (Dark Triad) içindeki en belirgin faktör olan büyükenmeci narsisizme sahip kişiler; başlangıçta karizmatik, çekici ve özgüvenli olsalarda aslında empati yoksunluğu ve manipülatif niyetlere sahiptirler [19]. Sosyal ilişkilerinde bir tehditle karşılaştıklarında veya beklentileri ilgiyi alamadıklarında bu kişiler "narsistik öfke" denilen yoğun bir saldırganlık yaşarlar. Bunun sebebi genellikle hatalarının dış faktörlerden kaynaklı olduğunu düşünerek başkalarını suçlama eğiliminde olmalarıdır [24]. Gelişimsel kökenlerine bakıldığında büyükenmeci narsisizmin temelinde ebeveynlerin çocuğu gerçek olamayacak şekilde idealleştirmesi ve sınırları belirtmemesinin önemli bir faktör olduğu görülmektedir [25]. Bu aşırı değer verme, çocuğun başkalarından üstün olduğu yönündeki inancını arttırmakta ve çocukların ileriki yaşamlarında da bir "hak kazanma" (entitlement) duygusuna dönüşmektedir [26]. Büyükenmeci narsisizmin iki farklı yöntemle çalıştığını vurgulayan Narsistik Hayranlık ve Rekabet Modeli (NARC)'a göre "Narsistik hayranlık" yöntemi sosyal çekicilik ve kendini tanıtmaya egoyu beslerken; "narsistik rekabet" yöntemi çatışma ve küçümseme yoluyla üstün olmayı amaçlar [27]. Sonuç olarak büyükenmeci narsisizm, sadece karakteristik bir özellik değil, kişinin kendisiyle ve toplumla kurduğu bağı derinden etkileyen, yüksek uyumsal görüntünün altında ciddi kişilerarası çatışmalar bulunduran patolojik bir durumdur [28]. Narsisizmin bir diğer boyutu olan Kırılgan narsisizm (vulnerable narcissism), literatürde sıklıkla "gizli narsisizm" (covert narcissism) olarak da adlandırılan ve büyükenmeci tipin aksine dışsal bir özgüven yerine içsel bir yetersizlik duygusuyla karakterize edilen karmaşık bir kişilik örüntüsüdür [17, s.370]. Miller ve ark. [20] tarafından yapılan ağ analizleri, bu yapının temelinde yüksek derecede nevrozizm, eleştiriye karşı aşırı duyarlılık ve kronik bir utanç duygusunun yattığını ortaya koymuştur. Kırılgan narsist bireylerin en belirgin bilişsel çarpıtması, kendilerini hem "çok özel ve eşsiz" hem de "dünya tarafından haksızlığa uğratılmış bir kurban" olarak görmeleridir [22]. Bu bireylerde büyükenmecilik (grandiosity), açık bir sergilemeden ziyade, başkalarından beklenen ancak bir türlü gelmeyen o "hak edilmiş hayranlığın" hayal edilmesi ve bu hayalin gerçekleşmemesi sonucunda derin bir kırgınlık yaşanması şeklinde tezahür eder [24]. Campbell ve Miller'ın [20] vurguladığı gibi, bu bireyler sürekli bir psikolojik acı, boşluk hissi ve düşük kendilik saygısı sarmalında yaşarlar. Kişilerarası ilişkilerde kırılgan narsisizm, genellikle kaçınan ve savunmacı bir sosyal tutumla kendini gösterir [21]. Bu kişiler en ufak bir olumsuz geri bildirimi dahi benliklerine karşı bir tehdit

olarak algılar ve sosyal ortamlarda yoğun düzeyde reddedilme korkusu yaşarlar [29]. Bireyin kendisini koruma amaçlı kendini geri çekerek sosyal izole etmesine veya ilişkilerinde pasif-agresif manipülasyon tekniklerine başvurmalarının altında bu neden yatar [17, s.370]. Kırılğan narsistik bireylerin empati kurma süreçleri de oldukça problemlidir; fakat büyülenmeci narsisizmde olduğu gibi diğerlerini nesneleştirmekten öte, bireyler burada kendi içsel acılarına ve savunma mekanizmalarına çok fazla odaklanırlar bundan ötürü de başkalarının duygularını göremezler [29]. Kırılğan narsisizmde bireylerin büyülenmeci narsist bireylerin tersine, özsaygılarını korumak için dışardan bir onaya ihtiyaçları vardır ve bu kişiler hayal kırıklığına uğramamak için boyun eğici davranışlarda bulunabilir [30]. Kırılğan narsisizmin gelişimsel temellerine bakıldığında genellikle "koşullu sevgi" sunarak aynı zamanda yüksek eleştirel tutumlar sergileyen ebeveynler sahip oldukları görülmüştür [25]. Erken çocuklukta maruz kalınan tutarsız ebeveyn ilgisi, duygusal ihmal, mükemmel olduğu takdirde başarının onaylanması gibi durumlar bu çocukların yetişkinlikte dış onaya bağımlı fakat eleştiriye karşı savunmasız bir benlik oluşturmaları [31]. Klinik boyut ele alındığında ise büyülenmeci narsisizme göre kırılğan narsisizmde daha yüksek düzeyde depresyon, anksiyete ve somatik belirtilerin olduğu görülmüştür [17]. Bu kişiler yaşadıkları yoğun utanç duygusu sebebiyle, kendine zarar verme davranışları ile öz-kıyım düşüncelerine sahip olabilir [32]. Sonuç olarak narsisizmin her iki türünde de, ifade etme şekillerinde belirgin farklar görülse temelde yaralı bir benlik yapısı bulunur ve sürekli yetersizlik hissine karşı koymaya çalışan bir savunma mekanizması çalışır [33, s.14].

3. YÖNTEM

Bu bölümde araştırmanın deseni, çalışma grubu, veri toplama araçlarının teknik özellikleri ve uygulanan istatistiksel analizlerden bahsedilmiştir.

3.1. Araştırmanın Modeli

Bu çalışma, verilerin sayısal olarak ifade edildiği ve değişkenler arasındaki ilişkilerin istatistiksel analizlerle test edildiği nicel araştırma yöntemiyle yapılmıştır. Nicel araştırma; sosyal olguları nesnelleştirerek ölçülebilir verilere dönüştüren ve kuramsal hipotezlerin test edilmesine olanak sağlayan bir yaklaşımdır (Karasar, 2020). Araştırma kapsamında, üniversite öğrencilerinin mevcut kırılğan narsisizm düzeylerini var olduğu şekliyle betimlemeyi ve bu düzeylerin demografik değişkenlerle olan ilişkisini saptamayı hedefleyen ilişkisel tarama modeli tercih edilmiştir (Büyüköztürk, 2018).

3.2. Çalışma Grubu (Örneklem)

Araştırmanın katılımcılarını üniversite dönemindeki toplam 240 öğrenci oluşturmaktadır. Araştırmaya

katılan üniversite öğrencilerinin cinsiyet dağılımı 120 kız 120 erkek şeklindedir. Araştırmayın katılımcıları sınıf düzeyi ve ekonomik düzey değişkenleri açısından farklı dağılıma sahiptirler. Bu araştırmaya katılımcı seçilirken gönüllülük faktörü esas alınmıştır.

3.3. Veri Toplama Aracı

Kırılğan Narsisizm Ölçeği (KNÖ): Katılımcıların kırılğan narsisizm düzeylerini ölçmek için "Kırılğan Narsisizm Ölçeği (KNÖ)" kullanılmıştır. Ölçek, 10 maddeden oluşmaktadır ve bu maddeler bireyin yetersizlik duygusu, utanç ve sosyal kaçınma gibi kırılğan narsistik özelliklerini ölçmeyi hedeflemektedir. Ölçek maddelerine "Sıklıkla başkalarının görüşlerini kişisel olarak yorumlarım." maddesi örnek olarak gösterilebilir. Ölçek, 5'li likert yapıya sahiptir (1= hiç katılmıyorum ile 5= tamamen katılıyorum). Ölçekte ters puanlanan bir madde bulunmayıp ölçekten alınabilecek en düşük puan 10, en yüksek puan ise 50'dir.

3.4. Verilerin Analizi

Toplanan veriler spss programıyla analiz edilmiştir. Elde edilen verilerin normal dağılım gösterip göstermediği test edildikten sonra normal dağılım gösterdiği belirlenmiştir. Verilerin analizinde cinsiyet değişkeni için yapılan karşılaştırmalar (120 kadın, 120 erkek) bağımsız örneklem t-testi, sınıf düzeyi ve ekonomik durum değişkenleri için ise Tek Yönlü Varyans Analizi (ANOVA) teknikleri kullanılmıştır.

4. BULGULAR

Araştırmanın bu bölümünde toplanan veriler analiz edilmiş, üniversite öğrencilerinin kırılğan narsisizm düzeyleri ile cinsiyet, sınıf seviyesi ve algılanan ekonomik durum değişkenleri arasındaki ilişkilerin parametrik testler aracılığıyla elde edilen analiz sonuçlarına yönelik bulgulara değinilmiştir.

Tablo-1:

Kırılğan Narsisizm Ölçeği Cronbach's Alpha Güvenirlik Analizi Sonuçları

Ölçek	Cronbach's Alpha	Madde Sayısı
Kırılğan Narsisizm	.894	10

Tablo-1 incelendiğinde, araştırmada kullanılan Kırılğan Narsisizm Ölçeği'nin iç tutarlık katsayısının oldukça yüksek (.894) olduğu görülmektedir. Alan yazında güvenirlilik düzeyinin .70'in üzerinde olması, ölçek aracının ölçmek istediği yapıyı hatasız ve istikrarlı bir şekilde ölçtüğünün kanıtı olarak kabul edilmektedir. Elde edilen bu katsayı, araştırma verilerinin bilimsel analizler için yeterli güvenirlilik düzeyine sahip olduğunu göstermektedir.

Tablo-2:

Katılımcıların Demografik Özelliklerine İlişkin Betimsel İstatistikler (Frekans, Ortalama ve Standart Sapma)

Değişken	N	Minimum	Maximum	Mean	Std. Deviation
Cinsiyet (Kadın, Erkek)	240	1,00	2,00	1,5000	,50100
Sınıf Düzeyi (1, 2, 3, 4)	240	1,00	4,00	2,5000	1,11800
Ekonomik Durum	240	1,00	3,00	2,0000	,70850

Tablo 2 de katılımcılara ait demografik özelliklerin betimsel dağılımı verilmiştir. Toplam 240

öğrencinin katılım sağladığı araştırmada, cinsiyet dağılımının (Ort=1.50) tam bir denge sağladığı ve

örneklemin %50 kadın, %50 erkek öğrenciden oluştuğu görülmektedir. Sınıf düzeyine yönelik ortalamaların 2.50 çıkması, araştırmanın üniversite eğitiminin tüm kad-
emelerinden (1, 2, 3 ve 4. sınıf) eşit sayıda öğrenciyi

kapsadığını doğrulamaktadır. Algılanan ekonomik du-
ruma ilişkin elde edilen bulgular ise, çalışma grubunun
ağırlıklı olarak orta gelir düzeyine sahip ailelerden
geldiklerini ortaya koymaktadır.

Tablo-3:

Kırılğan Narsisizm Puanlarının Cinsiyet Değişkenine Göre Bağımsız Örneklem t-Testi Sonuçları

Grup	N	X̄	S	t	p
Kadın	120	33,18	4,92	5,82	,003
Erkek	120	29,05	5,14		

Tablo-3 verileri değerlendirildiğinde, kırılğan narsisizm düzeyinin cinsiyet değişkenine göre istatistiksel olarak anlamlı bir farklılık gösterdiği saptanmıştır [t(238)=5.82, p<.05]. Puan ortalamalarına bakıldığında; kadın öğrencilerin kırılğan narsisizm düzeylerinin ($\{X\}=33.18$), erkek öğrencilerin

ortalamalarından ($\{X\}=29.05$) anlamlı derecede daha yüksek olduğu sonucuna ulaşılmıştır. Bu bulgu, kadın öğrencilerin reddedilme hassasiyeti ve sosyal onay ihtiyacı gibi kırılğan narsisistik eğilimleri erkek öğrencilere oranla daha yoğun deneyimlediklerini ortaya koymaktadır.

Tablo-4:

Kırılğan Narsisizm Puanlarının Sınıf Düzeyine Göre Tek Yönlü Varyans Analizi (ANOVA) Sonuçları

Değişken	Gruplar	N	X̄	F	p	Anlamlı Fark (Scheffe)
Sınıf Düzeyi	1. Sınıf	60	32,45	1,72	,164	-
	2. Sınıf	60	31,10			
	3. Sınıf	60	33,05			
	4. Sınıf	60	29,80			

Tablo-4 incelendiğinde, üniversite öğrencilerinin kırılğan narsisizm puanlarının öğrenim gördükleri sınıf düzeyine göre istatistiksel olarak anlamlı bir farklılık sergilemediği tespit edilmiştir [F(3, 236)=1.72, p>.05].

Tüm sınıf seviyelerinde benzer narsisistik eğilimlerin gözlenmesi, bu kişilik yapısının akademik kideden bağımsız olarak gelişimsel bir süreç sergilediği sonucuna ulaşılmıştır.

Tablo-5:

Kırılğan Narsisizm Puanlarının Ekonomik Düzey Değişkenine Göre Tek Yönlü Varyans Analizi (ANOVA)

Sonuçları

Ekonomik Durum	1. Düşük	60	37,24	14,32	,000	1 > 2, 1 > 3
	2. Orta	120	31,45			
	3. Yüksek	60	26,12			

Tablo 5'e göre, öğrencilerin kırılğan narsisizm puanlarının algılanan ekonomik düzeye göre anlamlı bir farklılık gösterdiği saptanmıştır [F(2, 237) = 14,32, p < .05]. Buna göre yapılan test sonuçlarına göre; ekonomik düzeyini "düşük" olarak tanımlayan öğrencilerin kırılğan narsisizm puanlarının ($\{X\}=37.24$), "orta" ($\{X\}=31.45$) ve "yüksek" ($\{X\}=26.12$) düzeydeki öğrencilere göre anlamlı derecede daha yüksek olduğu saptanmıştır. Bu bulgu, düşük gelir algısının bireylerde eksiklik hissi tetikleyebileceğini ve bu durumun dış onay arayışı ile karakterize olan kırılğan narsisistik savunmaları artırabileceğine işaret etmektedir (Zeigler-Hill vd., 2011).

5. TARTIŞMA ve SONUÇ

Bu araştırma üniversite öğrencilerinin kırılğan narsisizm düzeylerinin cinsiyet, sınıf düzeyi ve ekonomik düzey demografik değişkenlerle ilişkisini incelemeyi amaçlamıştır. Bu kapsamda elde edilen bulgular mevcut literatür ve kuramsal yaklaşımlar ışığında değerlendirilip tartışılmıştır. Araştırmanın ilk bulgularından biri cinsiyet değişkeninde kadın öğrencilerin kırılğan narsisizm puanlarının erkek öğrencilere göre istatistiksel olarak anlamlı bir farklılık göstermesidir. Bu durum toplumsal bakış açısının kadınları duygusal hassasiyete ve sosyal onay ihtiyacı arayışına girecek şekilde yetiştirilmesiyle ilişkilendirilebilir; çünkü kırılğan narsisizme sahip

kişiler öz saygılarını korumak için dış onaya ve geri bildirimlere ihtiyaç duyarlar. Literatürde kırılğan narsisizmin düşük özsaygı ve reddedilme duyarlılığı ile ilişkili olduğu göz önüne alındığında, kadın katılımcıların daha yüksek kırılğan narsisizm puanına sahip olması, eleştiriye karşı geliştirilen savunmacı bir mekanizma olarak yorumlanabilir. Araştırmanın bir diğer sonucu, öğrencilerin öğrenim gördüğü sınıf düzeyinin kırılğan narsisizm puanları üzerinde istatistiksel olarak anlamlı bir farklılık göstermediğidir. Bu bulgu, üniversite eğitimindeki sınıf düzeyi gibi akademik seviyelerden öte, narsistik özelliklerin gelişimsel süreçlerin çok daha erken dönemleriyle ilişkili olduğu görüşünü destekler nitelikte olabilir. Freud'un [4] belirttiği üzere narsisizm örüntüsünün temelleri bebeklik ve çocukluk dönemlerinde başlamakta, ebeveyn davranış ve tutumları ile erken dönemde yaşanan narsisistik zedelenmeler kişiliğin bu yönünü şekillendirmede etkili olmaktadır. Araştırmada öğrencilerin her sınıf düzeyinden, benzer puanlar alması, narsisizmin akademik seviyeden çok derinleşmiş kişilik örüntüleri ve bağlanma stilleriyle ilgili olduğunu gösterir nitelikte olabilir. Ekonomik düzey değişkenine bakıldığında ise, gelir düzeyini "düşük" olarak belirten katılımcıların en yüksek kırılğan narsisizm puanı sonucuna ulaşılmıştır. Kırılğan narsisizm kavramının; yetersizlik, boşluk hissi ve yoğun utanma duygularıyla ilişkili olduğu göz önüne

alındığında düşük ekonomik refah algısı, kişinin kendisini yaşlılarıyla kıyaslamasına ve "özel olma" arzusunun sosyal engellerden ötürü ketlendiği narsistik yaralanmayı derinleştiriyor olabilir. Kırılgan narsisizmin bireyin zayıf kendilik yapısıyla ilişkili olduğu bilinmektedir; ekonomik kısıtlılıklar ise bireyin kendisini yetersiz ve değersiz hissetmesine sebep olan dışsal bir stres kaynağı olduğundan kırılgan narsisizm düzeyini artırmada etken olabilir. Sonuç olarak, üniversite öğrencilerinde görülen kırılgan narsistik eğilimlerin temelinde, yetersizlik duygusu ve bu duyguya karşı geliştirilen bir savunma mekanizmasının yattığı görülebilir. Araştırma bulgularına göre; cinsiyet değişkeninde özellikle kadın öğrenciler ve ekonomik düzey değişkeninde düşük ekonomik refah yaşayan grupların, narsistik özellikleri daha çok barındırdığını göstermektedir. Üniversite ortamında öğrencileri benlik saygılarını koruma amacıyla dış onay arayışı veya sosyal kaçınma gibi yöntemlere yönelebilirler. Bu bağlamda yukarıda verilen tüm bilgilere dayanarak üniversite psikolojik danışmanlık birimlerinin özellikle bu gizlice kendini yansıtan narsistik özellikleri, hassasiyetleri tanınması ve risk altındaki gruplara yönelik öğrencilerin akademik ve sosyal uyumunu artırma amaçlı benlik saygısını artırmaya yönelik destekleyici ve önleyici çalışmalar planlanması önerilebilir.

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SOCIAL SCIENCES

EFFECTIVE LEADERSHIP PRACTICE IN 21ST CENTURY TO EVALUATE THE KEY TRAITS OF SUCCESSFUL LEADERS AS GLOBAL PERSPECTIVE

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Abstract

The normal workplace is no longer as conventional as it once was due to technological advancements and globalization in 21st century. In 21st century, with a globalization, the successful utilization of technology and contemporary lifestyles has become an essential component of leadership. Technology has a tremendous impact on all facets of human existence, and it is revolutionizing how contemporary leaders connect, manage everyday affairs, and conduct their businesses. Leadership is the capacity to express a vision, adopt the principles of that vision, and cultivate an atmosphere in which all individuals can achieve the organization's objectives and their own personal requirements. Organizational leaders are typically defined as individuals who possess command, position, control, governance and authority at the highest echelons of an organization. Nevertheless, this is entirely inaccurate. Contemporary leaders can make educated judgments, generate innovation, and remain ahead of the competition by leveraging technological improvements, which also enhances efficiency and productivity. They give significance on organizations, agencies, businesses, industries, or nations can get effective leadership style to achieve their mission and vision. Contemporary leaders involve and adopt novel tactics and concepts and are ready to change. Today organizations face many challenges in creativity and transformation. As a result, contemporary leadership approaches tend to be more appropriate, particularly in a global setting. The authors of this analytical study have taken an effort to determine the key traits/characteristics of contemporary leader thorough examination of associated problem and challenges of leadership in 21st century as global perspective, where advanced technology and globalization are vital.

Keywords: Traits, leadership, toxic workplace, innovation, courage, honesty

I. Introduction

Humans pursue meaning of life in the metrics of happiness in knowing and activities, where happiness is concerned in their feelings in the present and related to their satisfaction. This includes relationships, work, achievements, the people around us, level of pressure, zeal in life, and all other things that we care about and everything is integrated into the essence of human life.¹ Leaders are the individuals who motivate and inspire others with their behavior, style, and abilities. Modern leaders are surrounded by individuals that share their passion, drive, and thought process. They have genuine following, team members, and lovers; nonetheless, they are not motivated by fame or popularity. Their vision and objectives are evident, and they were implemented without the necessity of obtaining special privileges, rights, or positions. Modern leadership is not contingent upon one's status or position. Typically, they remain as a top executive who oversees the subordinates are compelled to adhere, even if their views and vision are in stark opposition. Contemporary leaders in 21st

century must embrace a modern way of thinking in order to meet these particular difficulties. The secret is innovation, courage, agility and balance. Today leaders need to be adaptable, receptive to change, and proactive is crucial. They need to establish a stronger connection with their team members in order to create an atmosphere where creativity flourishes and change is encouraged rather than feared. Today, leaders need to adopt a more people-centric management style rather than concentrating only on output; create creative methods of operation and tactics that suit the current situation; proactively introduce new procedures and encourage teams to welcome change.² In the modern leadership approach, leaders provide and ensure the power of data to boost team performance and drive business growth; fostering innovation, collaboration, and a sense of purpose while building resilient teams; focusing on self-development to continuously adapt and grow in a world that is constantly changing; and utilizing the potential of every team member. In this new era of leadership, it

¹ Hossain K A, (2025), NARRATIVE OF SIMPLE AND HAPPY LIFE, Journal of Liberal Arts and Humanities (JLAH) Issue: Vol. 6; No. 4; August 2025 (pp. 33-84) ISSN 2690-070X (Print) 2690-0718, available from:

Doi: 10.48150/jlah.v6no4. 2025.a1, accessed on 30 Dec 2025

² CoachHub, (2025) The Digital Coaching Platform, Modern Leadership Styles & Their Effect on Well-being, Available from: <https://www.coachhub.com/blog/modern-leadership-styles-their-effect-on-well-being> accessed on 13 Jul 2025

is impossible to overestimate the importance of good communication and, more crucially, active listening.³

There is a big difference between classical or traditional leadership, which is centered on titles and positions, and contemporary leadership, which is a way of life that influences, motivates, and inspires people. Once again, people may be unconvinced, unmotivated, and uninfluenced by the vision, objectives, ideas, and perspectives if command is too restrictive, which can lead to conflict and objection. A contemporary leader who can motivate their followers by outlining the realistic benefits and drawbacks of proposed activities, tactics, and plans is more likely to have their followers and teammates buy into their vision. So, instead of relying on influence, control, command, and order, contemporary leadership must be based on communication, relationships, attention, and caring. True, modern leadership is more of a way of life than a job description or title. It encompasses one's actions, beliefs, and perspective. In reality, contemporary leadership is less about rank and more about building relationships, committing to the team's goals, and coordinating efforts while also valuing and respecting each team member's unique perspective. This is when a leader possesses the character traits and demeanor necessary to make an impression. Contemporary leaders do not require any particular tie or connection to a position or social status in order to influence and persuade individuals to believe in them.⁴ Contemporary leaders don't need high-ranking titles to prove their effectiveness. The rise of technologies like IoT, AI, ML, DL, blockchain, big data, etc. is transforming the workforce, impacting fields such as law, engineering, and healthcare. Traditionally, leadership emphasized expertise, but that emphasis is shifting. Future leaders must focus on managing relationships and fostering collaboration within teams. The ability to communicate, motivate, and influence is essential for effectively managing human resources and benefiting both the company and its workers.⁵ Recent leadership becomes a powerful force when individuals are willing to harness their influence, articulate a compelling vision, and create a lasting impact.

Every successful venture/business lies effective leadership, and for this a driving force propelling organizations towards their strategic objectives. It is through people management that leaders cultivate an atmosphere conducive to productivity and engagement. However, in today's dynamic corporate landscape, the ability to adeptly manage people is as important as understanding the intricacies of the organization's business model and its objective.⁶ Significant changes in leadership content, delivery, and accessibility are being

made possible by technological breakthroughs. Today, advance technology including digitization, automation, Internet of Things (IoT), Artificial Intelligent (AI), Machine Learning (ML), Deep Learning (DL), blockchain, are significantly more intelligent than even the most brilliant and talented humans are considered a super-intelligence, superhuman intelligence, or hyper-intelligence. The kind or level of intellect that such an agent possesses can also be referred to as super-intelligence. Artificial general intelligence (AGI) research might lead to software with enough intelligence to self-reprogram and enhance its performance. The software would continue to get better as it became better, causing it to improve itself in a recursive fashion. During an intelligence explosion, its IQ would skyrocket, potentially surpassing that of humans by a wide margin. This situation was dubbed the singularity by science fiction author Vernor Vinge. After the technological singularity, what happens next is hard to anticipate or even understand because our intelligence and the power of super-intelligent computers are hard, if not impossible, to pin down. In the cyber security concern, in just a few short hours, AI, ML, DL or blockchain can create tens of thousands of harmful compounds. For this reason, we may see the advent of such complex technological developments or super-intelligence robots in the not-too-distant future. Hence, it is incumbent upon future leaders to provide them with the necessary tools. In today's tech-driven world, successful leadership need to be built them in a solid basis of fundamental principles. While technical know-how is obviously important, leaders should also model qualities like integrity, adaptability, equilibrium, etc. Leaders need to be able to roll with the punches since technology is always changing.⁷ It enables leaders to adapt to a constantly changing environment, accept new ideas, and grab opportunities as they arise. Leaders that excel at what they do manage to keep both human and technological factors in check.

The most successful managers and leaders are aware that their performance in their primary duties and their ability to overcome obstacles will be the primary criteria used to evaluate them in 21st century. The journey of leadership has been long, as obvious by a dynamic evolution from autocracy to democracy. In the early stages, the authoritarian leadership style was dominant. It left little room for team input, focusing instead on the unilateral execution of decisions. On the other hand, democratic leadership, accentuating team participation and inclusivity, offers a compelling alternative. These democratic leaders, nurturers of thought and creativity, drive their teams towards a shared vision, fostering a culture of collaboration. They harness

³ Hossain K A, (2025), Toxic Vs Contemporary Leadership Practice in 21st Century, Journal of Liberal Arts and Humanities (JLAH) Issue: Vol. 6; No. 4; August 2025 (pp. 33-84) ISSN 2690-070X (Print) 2690-0718, available from: Doi: 10.48150/jlah.v6no4.2025.a3, accessed on 30 Dec 2025

⁴ Hossain K A, (2015), Leadership qualities for 21st century leaders, Journal of Management, Social Science and Humanities, published on 19 May 2015, available at: <http://pearlresearchjournals.org/journals/pjmssh/archive.html>, accessed on 27 Dec 2025

⁵ Hossain K. A., (2015), "Essential Tips and Tactics of motivation, Journal of Management", Social Science and Humanities, Volume 1, Issue 1, April 2015, accessed on 27 Dec 2025

⁶ <https://www.skill-up.org/people-management-effective-leadership-skills/>, accessed on 27 Dec 2025

⁷ James, A. (2013). Transformational vs. transactional leadership theories: Evidence in literature. 355–361, accessed on 27 Dec 2025

the collective intelligence of their teams, making democratic leadership a preferred style in many contemporary organizations. The term "organizational toxicity" (OT) describes an environment where workers are unhappy and have issues, which in turn lowers their interest in and dedication to their work.⁸ The term "organizational toxicity" (OT) describes an environment where workers are unhappy and have issues, which in turn lowers their interest in and dedication to their work.⁹ Both individuals and organizations are badly affected by organizational toxicity, which is a major issue in today's workplaces. Organizational toxicity creates harmful working conditions that negatively affect employees' physical and mental health, leading to issues like depression and burnout. Therefore, it is clear that organizational toxicity is harmful to workers and may jeopardize businesses' viability.¹⁰ Because they fear rejection or criticism, employees in a lethal work place may be hesitant to express themselves, voice problems, or share ideas. Racism, dishonesty, and broken promises are just some of the unethical behaviors that can flourish in a hostile work environment.¹¹ Leadership is based on building relationships, and toxic work environments affect employees at all levels, from entry-level workers to high executives.¹² When a disease has spread throughout an entire organizational structure, removing the diseased head won't solve the problem. The initial stage in enhancing a culture is identifying its poisonous components. Leaders will waste time and energy trying to fix every part of company culture that some workers find annoying. On the contrary, they ought to zero in on the fundamental problems that make workers miserable to the point where they disengage, criticize, and eventually leave.¹³

In the realm of venture/business, leaders aren't just task managers. Actually, they are strategists, influencers, and change-makers and they arrange the smooth functioning of various elements of an organization, from human resources along with project management to risk management and strategic planning. The impact of competent leadership exceeds the boundaries of the team, influencing the entire organization's health and wealth management with optimum utilization. A contemporary leader in 21st century takes into account not just the output or completion of tasks, but also the professionalism and growth of their personnel. Contemporary leaders should treat their teams with the utmost respect and care. So, it's a way of life where one develops and improves their behavioral and action abilities to inspire and encourage team members to follow them.

Having a position of rank or title, along with the powers of command and control, does provide you the chance to lead, but it won't get you very far in the current leadership game.¹⁴ The purpose of this study is to offer a thorough study of leadership practice in 21st century, including the central role played by improved technology. It also covers the effects of modern technology, the effects of AI, ML, DL, IoT, and the fourth industrial revolution, robots, and all other smart technologies; the concept of contemporary leadership; and other issues pertaining to the development of leadership in this era. There are many challenges and gaps of true cognizant and contemporary leaders, whether in politics, religion, organization, business, education, or institution-everywhere in era of technological advancement. Famous or great leaders globally recognize the significant role of technology that plays in personnel management. It may facilitate team development and oversee work across all channels and locations globally. Actually, with continuous leadership training and mentoring, contemporary leaders can sharpen their skills and adapt to the demands of the developing economy. Through these measures, the future of leadership promises resilience, innovation, creative, effective, courage, balance and impactful change management. This article will focus on the difficulties and challenges of contemporary leadership with symptom of toxic leaders with the aim to evaluate a proposition of contemporary leadership practices with key traits of successful leaders in 21st century. Authors will try to answer the questions to fill the gaps of the study.

- a. What is the impact of technology on modern life and business?
- b. What is the impact of Toxic work environment?
- c. What is the sign of toxic leaders?
- d. What is the proposition of leadership practice in 21st century?
- e. What are the important traits of contemporary leaders in 21st century?

II. Literature Review

Background of Study on Leadership

The influential and renowned leaders in history for their mankind, civilization and motivation like Moses, who led the Israelites out of slavery in the Exodus from Egypt.¹⁵ Again, Mahatma Gandhi, who was a defender

⁸Frost P.J., (2003), *Toxic Emotions at Work: How Compassionate Managers Handle Pain and Conflict*. 1st ed. Harvard Business School Press; Boston, MA, USA: 2003. pp. 13–139, accessed on 27 Dec 2025

⁹Gunderman R.B., (2019), How neglect fosters workplace toxicity, *J. Am. Coll. Radiol.* 2019; 16:252–254, accessed on 27 Dec 2025

¹⁰https://www.researchgate.net/publication/372338777_How_Does_Organizational_Toxicity_Affect_Depression_A_Moderated_Mediation_Model, accessed on 27 Dec 2025

¹¹ <https://www.techtarget.com/whatis/feature/Signs-of-toxic-workplace-culture>, accessed on 27 Dec 2025

¹²<https://blackwells.co.uk/bookshop/product/Toxic-Organizational-Cultures-and-Leadership-by-Susan-Hetrick/9781032361291>, accessed on 27 Dec 2025

¹³ <https://sloanreview.mit.edu/article/why-every-leader-needs-to-worry-about-toxic-culture/>, accessed on 27 Dec 2025

¹⁴ Thunderbird School of Global Management, (2023), What is global leadership? Available from: <https://www.forbesindia.com/article/thunderbird/what-is-global-leadership/82793/1> accessed on 13 Jul 2025

¹⁵ Abrahams, Israel (2007), "Moses", in Berenbaum, Michael; Skolnik, Fred (eds.), *Encyclopedia Judaica*, vol. 14 (2nd ed.), Detroit: Macmillan Reference, p. 522, accessed on 13 Dec 2025.

of the principle of nonaggression as a means of revolution.¹⁶ On the other hand, Adolf Hitler, Nazi leader responsible for the Holocaust¹⁷ Nelson Rolihlahla Mandela, who dismantling the legacy of apartheid by fostering racial reconciliation and a multiracial democracy; groups, sets, and formed coalitions towards one goal. All of those leaders have different characteristics from each other. Some are pacifists, other activists, some conservative, some liberal, some make revolutions using words others using guns, some with a divine commission other against it, but all have something in common: the ability to involve thousands and millions of people and to lead their followers. Interestingly, every leader has their distinct way of influencing, guiding, supervising and motivating their own people or followers to the desired objective, and the delegation of activities or authority is shared with them, sometimes in a very obvious and open way. Freedom and empowerment, on the other hand, are not easy to transmit or share. The study by Conley and You (2018) points out that the leader who shares his management, involving his team in business decisions, improves the organizational climate and still retains employees in the organization to the extent of empowerment.¹⁸ Leadership, says Robbins and Judge (2025), is the ability to influence a group towards goal attainment.¹⁹ Peter Senge (1990) addresses the collective aspect of leadership, emphasizing that leaders conduct changes, and that is expected from true leaders.²⁰ The leaders' role is to be a projector, supervisor, and conductor. Avolio (2002) mentions that leadership is the ability to influence individuals and groups.²¹ Kotter J P (1988) said that "leading by example has a simple concept: words can be forgotten, but actions cannot". John C. Maxwell said, "A leader knows the way, goes the way and shows the way." Warren Bennis said, "Leadership is the capacity to translate a vision into reality." Mahatma Gan-

dhi said, "I suppose leadership at one time meant muscles, but today it means getting along with people. "McShane and Glinow (2005) separated the complicated topic of leadership into a few categories, including transformative, implicit, contingent, competent, and behavioral.²²

A survey of the literature on organizational change and leadership style has been performed by academics and researchers.²³ Several literature assessments have identified authoritarian, transformational, laissez-faire, servant, transactional, democratic, strategic, bureaucratic, consultative, and participatory leadership as accelerators of change management.²⁴ Subsequent research has shown that effective leadership is critical to the successful implementation of positive organizational changes.²⁵ The process of leading and directing followers along the path the leader has chosen in order to accomplish organizational goals is known as leadership.²⁶ The environment and culture of the organization have a huge impact on how executives behave. The common collection of values, presumptions, and beliefs that shape organizational behavior is referred to as organizational culture by Schein (2010).²⁷ On the other hand, workers' opinions and attitudes toward their workplace are related to organizational environment (Schneider, Ehrhart, and Macey, 2013).²⁸ According to Aycan et al. (2000), the cultural context affects the interaction between a leader and their subordinates, which in turn affects whether or not certain leadership philosophies are accepted. Furthermore, Einarsen et al. (2007)²⁹ stress how important it is to distinguish between harmful and ineffective leadership. While harmful leadership is intentional actions that injure others, ineffective leadership is characterized by a lack of knowledge or ability to accomplish desired goals. Schneider et al. (2013)³⁰ emphasized the importance of leaders in shaping the business environment and culture, emphasizing the need for inclusive and moral

¹⁶ Goswami, K. P (1971). Mahatma Gandhi A Chronology. Publications Division. p. 60. accessed on 13 Dec 2025

¹⁷ Maser, Werner (1973). Hitler: Legend, Myth, Reality. London: Allen Lane. accessed on 13 Dec 2025

¹⁸ Conley, S., and You, S. (2018). School organizational factors relating to teachers' intentions to leave: A mediator model. *Current Psychology*, 1-11, accessed on 13 Dec 2025

¹⁹ Robbins, S., and Judge Timothy A., (2025.), *Organizational Behavior*, Amazon publication, Available from: <https://www.amazon.com/Organizational-Behavior-14th-Stephen-Robbins/dp/0136124011> accessed on 13 Dec 2025

²⁰ Senge, Peter. (1990). *The Fifth Discipline*, dp: 0385260946, Amazon publication, Available from: <https://www.amazon.com/Fifth-Discipline-Peter-M-Senge/dp/0385260946> accessed on 13 Dec 2025

²¹ Avolio, Bruce J., and Bernard M. Bass, (2002), *Developing Potential across a Full Range of Leadership: Cases on Transactional and Transformational Leadership*, Mahwah: Erlbaum, available from: <http://www.netLibrary.com/urlapl.asp?action=summary&v=1&bookid=66188> accessed on 13 Dec 2025

²² McShane, S. L., & Glinow, M. V. (2005). *Organizational behavior: Emerging realities for the workplace revolution* (3rd ed.). New York: The McGraw-Hill Companies

²³ Ciulla, J. B., et al, (2020), The importance of leadership in shaping business values. *The Search for Ethics in Leadership, Business, and Beyond*, 153–163, accessed on 01 Jul 2025

²⁴ Bommer, W. H., et al, (2004), Setting the stage for effective leadership: Antecedents of transformational leadership behavior, *The Leadership Quarterly*, 15(2), 195–210, accessed on 11 Jul 2025

²⁵ Adams, D., et al, (2020), Principal leadership preparation towards high-performing school leadership in Malaysia, *Asian Education and Development Studies*, 9(4), 425–439, accessed on 27 Dec 2025

²⁶ Kadiyono, A. L., Sulistiobudi, R. A., Haris, I., Wahab, M. K. A., Ramdani, I., Purwanto, A., Mufid, A., Muqtada, M. R., Gufron, M., & Nuryansah, M. (2020). Develop leadership style model for Indonesian teachers' performance in Education 4.0 era. *Systematic Reviews in Pharmacy*, 11(9), 363–373, accessed on 11 Jul 2025

²⁷ Schein, E. H. (2010). *Organizational Culture and Leadership* (4th ed.). Jossey-Bass, accessed on 11 Jul 2025

²⁸ Schneider, B., et al, (2013), *Organizational Climate and Culture*, *Annual Review of Psychology*, 64, 361-388, accessed on 11 Jul 2025

²⁹ Einarsen, S., et al, (2007), *Destructive Leadership Behaviour: A Definition and Conceptual Model*. *The Leadership Quarterly*, 18, 207-216, accessed on 11 Jul 2025

³⁰ Hossain K A, (2024), AI is the smart solution for ocean resources preservation and maritime industry operation in modern era, *Scientific Research Journal (SCIRJ)*, Volume XII, Issue X, October 2024 ISSN 2201-2796, accessed on 11 Dec 2025

leadership.³¹ Fresh ideas on leadership, like many other parts of business, are being fostered by the rising understanding by companies throughout the globe that distant organizations and events have an influence on their operations.³² Corporate-level leaders, such as CEOs and upper management teams, have a problem due to the abundance of strategy options available for participating in global competition.³³ Traditional leadership and contemporary leadership differ in a few key ways. The authoritarian style of traditional leaders is typified by the lack of input or participation from others in the decision-making process.³⁴

However, contemporary leaders tend to take a more cooperative stance, which involves working together to achieve common goals and include others in the decision-making process. While traditional leadership is based on power and control, modern leadership places a higher priority on collaboration and teamwork. Task-oriented goals may also be given priority by traditional leaders, while people-oriented goals may be given priority by modern leaders. Traditional leaders often use a top-down approach, which entails making choices alone.³⁵ On the other hand, modern leaders are more likely to use a democratic or participatory style, which involves including others in the decision-making process. While modern leaders are more likely to use motivating techniques, traditional leaders may also be more authoritarian and employ harsher methods to impose their will.³⁶ While contemporary leaders could be more likely to use informal power, traditional leaders might be more likely to use official authority to sway others. There aren't many clear benefits to using a traditional leadership paradigm as opposed to a contemporary one. Because of its duration, traditional leadership techniques are often more well-liked and accepted

by staff. Because it promotes more stability and order, a conventional leadership approach could be beneficial in companies with intricate hierarchies or large operations. Traditional leadership styles, which are more formal and have distinct lines of power, may help with communication and decision-making.³⁷ Toxic leadership are only a few of the ideas used in the literature to describe the negative aspects of leadership (Einarsen, Skogstad, Leseth and Aasland, 2002; Einarsen, Aasland and Skogstad, 2007),^{38,39} toxic leadership, and bullying (Rayner & Cooper, 1997)⁴⁰, (Lipman Blumen, 2005)⁴¹. On the other hand, as compared to traditional leadership, modern leadership has distinct drawbacks. It's possible that leaders nowadays don't have as much authority or prestige. Followers of modern leaders may become less motivated.⁴² Modern leadership techniques may be less effective in certain situations. Individual achievements could get more attention than team performance.⁴³ However, compared to more traditional leadership techniques, there are certain advantages to using a modern leadership paradigm.

Modern leaders are often more focused on achieving results than their predecessors.^{44, 45} This implies that they would rather implement strategies that help their businesses than preserve the status quo. Teamwork is often valued more highly by modern leaders than solo success.⁴⁶ This might lead to an increase in creativity and invention as well as a more cohesive and effective

³¹ Bilal Zaghmout, (20240, Unmasking Toxic Leadership: Identifying, Addressing, and Preventing Destructive Leadership Behaviours in Modern Organizations, Management Studies, York St John University, London, UK, accessed on 11 Dec 2025

³² M. F. Peterson, (1988), Organization development programs in Japan and China based on the Performance-Maintenance (PM) theory of leadership Organizational Dynamics, accessed on 30 Jul 2025

³³ G. Hofstede, (1980), Motivation, leadership, and organizations: Do American theories apply abroad? Organizational Dynamics, accessed on 11 Sep 2025

³⁴ Hidayat Rizvi, (2024), Traditional leadership vs modern leadership, difference, pros and cons, Leadership and Negotiation, Available from: <https://hidayatrizvi.com/traditional-leadership-vs-modernleadership-difference-pros-and-cons/> accessed on 11 Jul 2025

³⁵ Crick, F. (1995), The Astonishing Hypothesis: The Scientific Search for the Soul, Simon & Schuster, New York

³⁶ Yukl, G., et al, (1992), Theory and research on leadership in organizations, Palo Alto, CA: Consulting Psychologist, accessed on 11 Jul 2025

³⁷ Hidayat Rizvi, (2024), The Ultimate Guide to Understanding Contemporary Leadership Theories, Available from: <https://hidayatrizvi.com/contemporary-leadership-theories/> accessed on 11 Jul 2025

³⁸ Einarsen, S., Skogstad, A., Leseth, A. M. S. B., & Aasland, M. S. (2002). Destructive leadership: A behavioural model. *Forskningved Institutt for samfunnspsykologi*, 55–59, accessed on 17 Jul 2025

³⁹ Vermani M., (2022), Tackling workplace toxicity, *Empl. Benefits Wellness Excell*, 2022;9:36–38, accessed on 17 Jul 2025

⁴⁰ Rayner C, et al, (1997), Workplace bullying: Myth or reality– Can we afford to ignore it? *Leadership and Organization Development Journal* 18(4): 211–214, accessed on 19 Jul 2025.

⁴¹ Lipman-Blumen, J. (2005). *The Allure of Toxic Leaders: Why We Follow Destructive Bosses and Corrupt Politicians – and How We Can Survive Them*. Oxford: Oxford University Press

⁴² Indradevi Balasundaram, (2020), Toxic Leadership over the Years – A Review, Available from: https://www.researchgate.net/publication/338800769_Toxic_Leadership_over_the_Years_-_A_Review, accessed on 11 Jul 2025

⁴³ Harris, K. J., Kacmar, K. M., and Zivnuska, S. (2007), An Investigation of Abusive Supervision as a Predictor of Performance and the Meaning of Work as a Moderator of the Relationship. *The Leadership Quarterly*, 18, 252–263, accessed on 11 Jul 2025

⁴⁴ Bandura, A., (1977), *Social Learning Theory*, Prentice Hall, accessed on 11 Jul 2025

⁴⁵ Zangaro, G. A., et al, (2009), Recognizing and overcoming toxic leadership, Available from: <http://rnjournal.com/journal-of-nursing/recognizing-and-overcoming-toxic-leadership>, accessed on 13 Oct 2025

⁴⁶ Hidayat Rizvi, (2024), Leadership Tactics and Strategy for the Modern Day, Leadership and Negotiation, Available from: <https://hidayatrizvi.com/leadership-tactics-and-strategy-formodern-days/> accessed on 13 Jul 2025

team. Modern leaders often prioritize ongoing education for both themselves and their employees.⁴⁷ In addition to learning new skills and knowledge, this helps them stay up to date on the latest developments and trends in their fields. Rather than just only controlling their employees, modern leaders often try to empower them. Consequently, this might lead to improved motivation, work satisfaction, and productivity. Generally speaking, modern leaders are open to change in both how they handle assignments and the goals they set for their companies. This allows them to take advantage of quickly shifting environments and quickly adapt to new circumstances and opportunities. The existing literature on the concept of virtual teams, contemporary/advanced technology, and e-leadership will be assessed in this research.⁴⁸ Recent studies on e-leadership have shown that the goals of leadership have not changed. On computer-mediated virtual teams that are geographically and temporally separated, the new e-leader must, nevertheless, carry out these goals electronically.⁴⁹ It is common to commend leadership as the driving force that shapes the destiny of teams, companies, and civilizations. Effective leaders inspire and motivate their followers, creating an environment that is conducive to development and productivity.⁵⁰ However, not all leaders are created equal. Toxic leadership is a horrible phenomenon that lurks in the dark corners of leadership, clouding the events and people it impacts.⁵¹ The phrase toxic leadership has garnered more attention and public concern in recent years.⁵² It includes a variety of behaviors and traits shown by leaders that create a poisonous atmosphere characterized by dysfunction, fear, and distrust rather than supporting their staff.⁵³

Toxic leadership has far-reaching effects that extend beyond its direct area of influence, impacting both the macro and micro facets of institutional culture and performance. In addition to more covert, nonviolent actions that are often seen in business environments, toxic leadership may manifest in a number of ways, such as overt aggression and pervasive toxicity.⁵⁴ The variety

of detrimental behaviors has inspired a number of academics to develop taxonomies of toxic leadership. Instead of characterizing toxic leaders, as was previously done by Whicker (1997) and Kellerman (2004), these taxonomies, as proposed by Williams (2005), Schmidt (2008), and Pelletier (2009), concentrate on describing certain behaviors.⁵⁵ In order to provide a worldwide perspective on modern leadership, the goal of this inquiry is to analyze and evaluate organizational behavior, global culture, societal change, globalization, traditional, modern, toxic, and effective leadership styles and practices. Reviewing books, journals, and other study materials, assessing primary and secondary data, and integrating the ideas and opinions of current academics will all help accomplish this. In order to prevent toxic environments, the researcher in this work has thoroughly researched and investigated leadership positions in the modern period and their contribution to strategically formed contemporary businesses. In the period of the fourth industrial revolution, or 4IR, research has also been done to support leadership styles and efficiency levels in relation to advanced technical innovation and organizational strategy.⁵⁶ The examination and arguments will center on the ways in which leaders' dependability, efficiency, activity, style, and action impact companies. Efforts will be made to demonstrate how technical advancements and management improvements to leadership in a competitive global market led to strategically evolved enterprises. In order to successfully navigate the complexities of modern leadership practice and challenges, as well as to succeed in the age of smart technology, this research also encourages a shift toward the acknowledgment and integration of global perspectives from many locations.⁵⁷

Impact of Technology on Leadership

Building technology that mimics human intelligence is obviously a good idea, but there are many different kinds of imitation. There are differing opinions among scientists regarding the best way to create AI systems that mimic human behavior. Some advocate

⁴⁷ Adem Yavaş, (2016), Sectoral Differences in the Perception of Toxic Leadership, *Procedia - Social and Behavioral Sciences*, Volume 229, 19 August 2016, Available from: <https://www.sciencedirect.com/science/article/pii/S1877042816310722> accessed on 11 Jul 2025

⁴⁸ Lin, C.-P., et al, (2010), Perceived job effectiveness in cooperation: A survey of virtual teams within business organizations. *Computers in Human Behavior*, 26, 339-344, accessed on 11 Sep 2025

⁴⁹ Raja Hashaam Khan, (2023), 10 Must-Have Leadership Discussion Topics for Rising Talent, Available from: <https://www.togetherplatform.com/blog/10-must-have-leadership-discussion-topics-for-rising-talent> accessed on 13 Nov 2025

⁵⁰ Christina Lattimer, (2023), A Comprehensive Overview of Leadership for New and Experienced Leaders, Available from: <https://peopledevelopmentmagazine.com/2023/01/08/comprehensive-overview-of-leadership/> accessed on 13 Nov 2025

⁵¹ Yukl, G. (2006). *Leadership in organizations* (6th ed.). Upper Saddle River: Pearson, accessed on 11 Jul 2025

⁵² Nauman, S., Khan, A. M., and Ehsan, N. (2009), Patterns of empowerment and leadership style in project environment.

International Journal of Project Management, 28, 638-649, accessed on 21 Jul 2025

⁵³ Goulet, L. R., and Frank, M. L., (2002), Organizational commitment across three sectors: Public, non-profit, and for-profit. *Public Personnel Management* 31(2), 201-210, accessed on 23 Nov 2025

⁵⁴ Einarsen, S., Aasland, M. S., and Skogstad, A., (2007), Destructive leadership behaviour: A definition and conceptual model. *The leadership quarterly*, 18(3), 207-216, accessed on 11 Sep 2025

⁵⁵ Kellerman, B. (2004). *Bad leadership: What it is, how it happens, why it matters*. Harvard Business Press

⁵⁶ Srivastava R.V., (2021), The Matthew effect in talent management strategy: Reducing exhaustion, increasing satisfaction, and inspiring commission among boundary spanning employees. *J. Bus. Ind. Mark.* 2021; 37:477-496, accessed on 13 Jul 2025

⁵⁷ Hossain K A, (2025), Appraise the Contemporary Leadership Practice in the Era of Smart and Advanced Technology, *International Journal of Science, Technology and Society*, 2026, Vol. 14, No. 1, pp. 21-51, available from: <https://doi.org/10.11648/j.ijsts.20261401.13>, accessed on 27 Dec 2025

for a synthetic model that closely resembles human biology, while others propose using methods like Whole Brain Emulation to achieve this goal (or WBE). The majority of humanity's greatest discoveries were the result of either a single scientist making a significant advance or of massive multinational cooperation. Rapid resolution of the obstacles to AI and WBE by a small number of scientists will be likely led to the creation of a single super-intelligent computer. Reason being, such a group might be compelled to operate in secrecy due to the highly competitive nature of the field. We should examine ways to improve and implement general intelligence technologies before we freak out about the approaching machine-led end of the world. Machines that can execute tasks that now require human intelligence and dexterity will likely become mass-produced at low cost as technology becomes more accessible and affordable. What this means is that machines will eventually supplant humans in every job and will be easy to replace once they do. It's obvious that a fully robotic workforce would revolutionize the economy, our way of life, and our wants and needs. When machine labor becomes the standard, wages will fall so low that no one can survive on a paycheck. In addition, the small number of companies that hired mechanical workers would amass substantial wealth. Returning to an earlier point, the fate of that funding is contingent upon whether SI is conceived by an exclusive group or the product of a gradual shared effort. Assuming the former is correct, the majority of people would have to resort to renting out their homes or living off of pensions and savings if they wanted to make ends meet. Thus, there are several safety concerns associated with SI development, and the worst-case scenario is that it might wipe humans off the face of the earth. Considering the reason behind the SI we create can help us take some measures, but it won't be enough on its own.

Four main features define the term "automatization" in the context of industrial production: 1) Robots manage the manufacturing process. The employment of smart machines will eventually lead to the complete automation of industrial processes, with people being involved in production only in rare instances. An example of this is the so-called "smart factory," a kind of manufacturing facility that uses minimal or no human workers. 2) One of the main features of Industry X is real-time production. 4.0. An intelligent machine determines the most efficient use of the production facility's resources. The production process has low lead times and can avoid standstills (apart from those caused by technical problems). Synchronization of resources (information, materials, and goods) is demand-driven across the value creation chain. The system orders more materials if the stock falls below a certain level, even though stocks are kept to a minimum. In the same way,

the machine reduces storage costs by producing finished goods in response to incoming orders and general demand. 3) The dispersion of manufacturing. In essence, the machine can organize itself. The manufacturing units are part of this network. Complete automation extends to both material planning and order processing. 4) Customization of manufacturing processes down to a single unit batch. The next generation of machines will have limited personalization capabilities, but they will be able to handle most requests. Humans are not needed to make any adjustments to the machines. Consequently, there will be no more changeover times. To meet the needs of its customers, the smart factory either incorporates new parts or, within the framework of optimal distribution, changes specific steps in the production process.⁵⁸ As a result of their autonomous connection with one another through networks and sensors, the phrase "Industry 4.0" refers to the optimization of production process components (machines, operating resources, software, etc.). In theory, this should help the business compete better on a global scale by lowering production costs, especially in the area of personnel planning. Some well-known examples from the realm of AI and robotics include self-driving cars, delivery drones, 3D printers, and so-called "smart factories," which can create extremely complicated objects from a single template without modifying the production process or requiring any kind of human intervention.

Some well-known examples of service models are social media sites like Facebook and Amazon Mechanical Turk, on-demand marketplaces like Uber and Airbnb, and content sharing platforms like Spotify, Netflix, and carpooling. According to research, the industry's revenue will increase twentyfold in the next decade just as a result of service sharing. While traditional industries were able to advance because to mass production and economies of scale, the rise of monopolies in the modern information economy is a direct result of networking effects.⁵⁹ Observing our surroundings today, it is evident that our society is evolving due to the integration of AI and IoT in everyday operations. For instance, when visiting a healthcare facility, an AI-powered device can check our pulse, and while shopping online, we encounter personalized product recommendations generated by AI tools. These illustrations only touch the surface of the advantages AI brings to our daily lives. In the future, we can expect even greater contributions from AI as other organizations, service sectors, and industries adopt this transformative expertise to enhance each aspect of social activity and workflow.⁶⁰ AI can enhance and expedite procedures across communities, societies, countries, and globally by improving workplace efficiency, supporting better decisions, or offering direct assistance. It can detect and re-

⁵⁸Hossain K A, (2023), Analysis of Present and Future Use of Artificial Intelligence (AI) in Line of 4th industrial Revolution (4IR), Scientific Research Journal 11 (8), ISSN: 2201-2796, Aug 2023, accessed on 27 Dec 2025

⁵⁹Bloomberg, (2016), available at: www.bloomberg.com/news/videos/2016-05-20/forward-thinking-march-of-the-machines, accessed on 27 Dec 2025

⁶⁰<https://www.thedailystar.net/recovering-covid-reinventing-our-future/blueprint-brighter-tomorrow/news/the-economic-impacts-the-4ir-bangladesh-2960641>, accessed on 27 Dec 2025

solve problems that might go unnoticed or be challenging for humans to manage alone. Nonetheless, some individuals remain skeptical of AI's benefits, fearing it could cause job losses and diminish human intelligence. In truth, AI's primary advantages include increased speed, accuracy, efficiency, and scalability. **Many current jobs will be obsolete in the next quarter of a century due to the 4IR's revolutionary impact on many different types of industries and services. Academic and learning institutions are not immune to the effects of these developments, and we must be aware of them.**⁶¹ A world where social media, cloud computing (internal and external), AI, ML, DL, IoT, and big data (Big Data) offer both opportunities and problems to conventional educational institutions is now facing all graduates. Institutions of higher education and learning are contemplating their own demise, especially in relation to service, as students think about life beyond graduation or diploma.

The world is being changed by practically AI-powered modern technologies to the extent that societal concepts like "post-work" are becoming more and more indicative of the modern day. Competencies needed in this era are different from those in the Third Industrial Revolution (when the primary engine was IT). By the conclusion of the next seven years, the artificial intelligence market is predicted to be worth \$15 trillion. Mass layoffs of unskilled workers with traditional education and training are imminent.⁶² In contrast, the next several years will see the creation of millions of occupations using contemporary and high-tech skills.⁶³ Imagine a world where AI not only revolutionizes industries but also sparks the creation of exciting new job opportunities! This powerful technology has the potential to transform our economy, driving productivity and efficiency like never before. Embracing AI could lead us to a future filled with innovative roles that empower individuals and enhance our work lives. The possibilities are endless!⁶⁴ The advancement of technology frequently results in the elimination of specific jobs, leading to a complex and individualized world, especially with the rise of AI. It is probable that there will be an insufficient number of employment opportunities for everyone in the future. Therefore, it is crucial for the new generation to receive education in advanced technology and develop valuable skills. As a result, transforming the current education system is essential to implement practical solutions.⁶⁵ AI has the potential to be both knowledge- and data-driven. When applied universally,

knowledge inference represents the next big thing in artificial intelligence. New research directions and standard extensions might emerge as a result of several major worries about machine learning in 5G and future networks.⁶⁶ An absolute assurance of safety is necessary for AI to gain widespread use and continue to improve. We need to portray AI in a way that fosters understanding and trust while safeguarding human and civil rights because it will soon be employed in healthcare and transportation.⁶⁷ Conversely, privacy, security, and ethical considerations should all be addressed by policies and standards. Therefore, international communities should work together to advance AI for the good of humanity. It appears improbable that all human jobs will be replaced by AI as it increasingly finds its way into the workforce. Instead, a large number of industry watchers anticipate a future in which workers exhibit ever-increasing levels of specialization. Creativity, problem-solving, and qualitative abilities, which automation cannot now provide, will be more important in these occupations in the future. People will always be required to work in the sector, but as technology progresses, their specific duties may also evolve. There will be a rise in the demand for people with certain skill sets, and a number of these occupations will call for highly technical expertise.

Impact of Toxic Work Environment on Leadership

As is well known, toxic workplaces cause employees to feel devalued, unloved, and unmotivated. The entire workforce may be impacted by this negativity, which can spread swiftly and hinder cooperation and teamwork. Nurses' silence inside the legal system and emotional exhaustion are the results of toxic leadership behaviors. In actuality, it is detrimental to every firm. Therefore, toxic leadership should be avoided since it poses a serious risk to any firm. Negative emotions such as punishment, rejection, guilt, defensiveness, and humiliation are common in toxic work situations. Due to the negative behaviors exhibited by both management and coworkers, employees struggle to function effectively in this environment. Common actions encompass berating, manipulating, screaming, and bullying. Workplaces that are hostile, sexist, racist, xenophobic, and otherwise harmful to employees are difficult to find. Workplace stress and burnout are both exacerbated by hostile work environments. In an effort to stave off burnout, some workers may do the bare minimum at work or even quit quietly.⁶⁸ Toxic events are present in every company to some extent, but ignoring them causes workers to lose motivation, creativity, and

⁶¹ <https://nntc.digital/blog/4ir-how-to-exploit-the-fourth-industrial-revolution/>, accessed on 03 Jan 2026

⁶² Kurzweil Ray, (2005), *The Singularity is Near: When Humans Transcend Biology*. New York: Viking. ISBN 978-0-670-03384-3, accessed on 03 Jan 2026

⁶³ Harris Karen, et al, (2018), "Labor 2030: The Collision of Demographics, Automation and Inequality," Bain and Company Reports, accessed on 03 Jan 2026

⁶⁴ Pablo Padula, (2023), *Are You Going to Lose Your Job to Artificial Intelligence?* Amazon Digital Services LLC - Kdp, ISBN:9798391007401, accessed on 03 Jan 2026

⁶⁵ Alexander J. Means, et al, (2020), *Education and Technological Unemployment*, Springer Nature Singapore,

ISBN:9789811362255, 9811362254, accessed on 03 Jan 2026

⁶⁶ 5G mobile network architecture for diverse services, use cases, and applications in 5G and beyond, EU co-funded project, available at, <https://www.5gmonarch.eu>, accessed on 03 Jan 2026

⁶⁷ A definition of AI: main capabilities and disciplines. High-Level Expert Group on Artificial Intelligence, European Commission, April 2019, accessed on 03 Jan 2026

⁶⁸ <https://www.techtarget.com/whatis/feature/Quiet-quitting-explained-Everything-you-need-to-know>, accessed on 03 Jan 2026

output^{69,70}; As a result of the detrimental impacts on their physical and mental health, people may suffer from problems including anxiety, stress, depression, and burnout syndrome (BS), and their relationships with the company may be strained.⁷¹ Despite its reputation as an OT-related issue, BS is, at its heart, an ever-changing process.⁷² It also includes weariness⁷³, depersonalization⁷⁴ when it comes to one's own achievements and self-esteem.⁷⁵ Additionally, BS can be defined as a syndrome of physical and emotional exhaustion, leading employees to have negative attitudes toward their jobs, while their desire for engagement decreases.⁷⁶ People who face BS often feel powerless, despairing, and overwhelmed⁷⁷. Stress resulting from OT in the relationship between OT and BS plays a crucial role, as stress is one of the harmful effects that OT can have on employees⁷⁸.

The prolonged persistence of stress is one of the primary reasons for the development of BS⁷⁹. Schaufeli and Enzmann actually state that burnout is the result of chronic work-related stress. Several studies in the literature support these arguments, revealing that OT positively affects BS^{80,81}. BS is a consequence of OT that affects more than just workers.⁸² BS is, at the same time, one of the main causes of depression⁸³. BS and depression are sometimes used interchangeably because of their similarities. Although some studies indicate that BS leads to depression, others suggest that depression can cause BS⁸⁴. It is fairly uncommon for companies to go through a succession of chief executive officers (CEOs) in search of the perfect rescuer when they replace a dysfunctional leader. On the Titanic, they are

essentially switching places. Though consultants and coaches may manage the symptoms of poison, they will not achieve long-term success unless they tackle the causes of toxicity. Depending on the individual, their work habits, and the things that set them off, the telltale symptoms of a toxic work environment can be different. Negative effects on workers' health from being in a toxic workplace for an extended period of time are real. Headaches, sleeplessness, gastrointestinal problems, and compromised immune systems are some of the stress-related health problems that people often experience. Employee morale suffers, and absenteeism increases as a result, ultimately reducing overall productivity.⁸⁵ The indicators of a toxic work environment can differ depending on individual employees, their work styles, and personal triggers. Extended exposure to such an environment can have significant repercussions on an employee's physical health. Common stress-related ailments, including headaches, insomnia, digestive problems, and weakened immune systems, often arise. These issues not only affect individual employees but also contribute to higher absenteeism, ultimately impacting overall productivity.⁸⁶ On the other hand, leaders should watch for these signs of a toxic work environment.

A person is not a leader if they lack or have not developed the ability to encourage or influence others. To be a modern leader, one does not need to have riches, rank, position, education, power, or anything else. He or she is guided in the correct route by positive instincts such as charisma and the ability to influence and persuade. Being a leader is more of a mindset than

⁶⁹Bailey D., et al, (2008), *Sustaining Our Spirits: Women Leaders Thriving for Today and Tomorrow*. NASW Press; Cary, NC, USA: 2008. pp. 14–37, accessed on 03 Jan 2026

⁷⁰Rasool S.F., (2021), How toxic workplace environment effects the employee engagement: The mediating role of organizational support and employee wellbeing. *Int. J. Environ. Res. Public Health*, 2021;18:2294, accessed on 03 Jan 2026

⁷¹Maslach C.A., (1998), Multidimensional theory of burnout. In: Cooper C.L., editor. *Theories of Organizational Stress*. 1st ed. Oxford University Press; Oxford, UK: 1998. pp. 68–87, accessed on 03 Jan 2026

⁷²Vermani M., (2022), Tackling workplace toxicity, *Empl. Benefits Wellness Excell*, 2022;9:36–38, accessed on 03 Jan 2026

⁷³Schilpzand P., et al, (2016), Workplace incivility: A review of the literature and agenda for future research. *J. Organ. Behav.* 2016; 37:57–88, accessed on 03 Jan 2026

⁷⁴Karwowski W., (2006), Toward an operational prevention of chemical risk in the working environment. In: Healthcare I., Karwowski W., editors. *International Encyclopedia of Ergonomics and Human Factors-3 Volume Set*, CRC Press; Boca Raton, FL, USA: 2006, pp. 746–753, accessed on 03 Jan 2026

⁷⁵Freudenberger H.J., (1974), Staff burn-out. *J. Soc. Issues*. 1974; 30:159–165, doi: 10.1111/j.1540-4560.1974.tb00706.x., accessed on 03 Jan 2026

⁷⁶Maslach C., (1981), The measurement of experienced burnout. *J. Occup. Behav.*, 1981;2:99–113, accessed on 03 Jan 2026

⁷⁷Schaufeli W.B., (2002), An overview of 25 years of research in theorizing. In: Schabracq M.J., Winnubst J.A.M.,

editors, *The Handbook of Work & Health Psychology*. Wiley; Hoboken, NJ, USA: 2002. pp. 383–425, accessed on 08 Jan 2026

⁷⁸Colligan T.W., (2006), Workplace stress: Etiology and consequences. *J. Workplace Behav. Health*. 2006;21:89–97. doi: 10.1300/J490v21n02_07, accessed on 08 Jan 2026

⁷⁹Maslach C., (2001), Leiter M.P. Job burnout. *Annu. Rev. Psychol.* 2001;52:397–422, accessed on 08 Jan 2026

⁸⁰Koropets O., (2020), *The Impact of Toxic Management on Staff Burnout*. Atlantis Press; Paris, France: 2020. pp. 121–131, accessed on 08 Jan 2026

⁸¹Moss J., (2020), Rethinking burnout: When self care is not the cure. *Am. J. Health Promot.* 2020;34:565–568, accessed on 08 Jan 2026

⁸²Rasool S.F., et al, (2021), How toxic workplace environment effects the employee engagement: The mediating role of organizational support and employee wellbeing. *Int. J. Environ. Res. Public Health*. 2021;18:2294, accessed on 08 Jan 2026

⁸³Srivastava R.V., (2021), The Matthew effect in talent management strategy: Reducing exhaustion, increasing satisfaction, and inspiring commission among boundary spanning employees. *J. Bus. Ind. Mark.* 2021; 37:477–496, accessed on 11 Jan 2026

⁸⁴Bauernhofer K., et al, (2018), Weiss E.M. Subtypes in clinical burnout patients enrolled in an employee rehabilitation program: Differences in burnout profiles, depression, and recovery/resources-stress balance. *BMC Psychiatry*. 2018; 18:10, accessed on 11 Jan 2026

⁸⁵<https://www.linkedin.com/pulse/toxic-leadership-new-look-solutions-dr-cherry-collier/>, accessed on 11 Jan 2026

⁸⁶<https://bhiveworkspace.com/workplace-toxicity-and-how-it-hampers-employee-performance/>, accessed on 11 Jan 2026

a title, position, or prestige. It has more to do with a person's conduct, disposition, outlook, style, and personality than with his or her rank, title, or appointment. The way that a person inspires, motivates, and influences others is the epitome of modern leadership. In all honesty, the concept of command and control does not fall under the purview of contemporary leadership. By inspiring or encouraging coworkers, team meetings, and business partners with one's own passion, one might get inspiration or stimulus to mirror or emulate the same in others. Once more, a contemporary manager turns into a social bonder, relationship healer, and human connector. A contemporary manager needs to become competent in identifying and utilizing employees' resources and strengths. Today's leaders must become more of an enabler by closely examining each employee's strengths and abilities. In the current era, with its many organizational perspectives and complex corporate landscape, the primary responsibility of managers and leaders is to facilitate, support, and even repair connections. To provide their staff with guidance, orientation, counsel, and familiarity, they must listen to them as a good coach would. The focus naturally turns inside in pursuit of stability and security when external circumstances become complicated and perplexing. In actuality, the primary responsibility of management in the future will be to establish a worldwide social framework that provides guidance and orientation to all employees. Contemporary leaders need to assign everything else and focus on the most crucial responsibilities that only they can complete. They can optimize the value they add to the organization by knowing what those special values are for them and assigning everything else to others. This contributes to a leader's growing self-awareness and comprehension of their unique leadership brand.

III. Sign and Symptom of Toxic Leaders and Proposition

A toxic leader is one who fosters a toxic work environment via the employment of authoritarian and oppressive management practices. Businesses frequently face both immediate and distant repercussions as a result of toxic leadership's unfriendly work culture. Toxic and destructive CEOs often cause high turnover rates, fatigue among employees, low innovation and productivity, unhappiness within teams, and bullying in the workplace. Leaders that display toxic conduct often suffer from low self-esteem and an unhealthy obsession with control, which manifests itself in micromanagement practices that undermine employees' sense of value and autonomy. Toxic CEOs, in their attempt to establish dominance, produce an unhealthy business

culture rather than a collaborative and constructive one.⁸⁷ A culture of trust and delegation can help leaders' combat toxic leadership. Working life isn't complete without bad supervisors. Anyone who has ever dealt with such leaders cannot possibly judge the current situation. But this piece paints a picture of that kind of leadership. Toxic CEOs appear to be all too prevalent in businesses big and small. Additionally, there is evidence to support the claim. Ohio State University researchers recently tried out teams without a designated leader to see how well they could complete a task. A worrying trend emerged as the researchers observed the groups' interactions.⁸⁸ It seemed like most of the groups' leadership positions were filled by narcissistic, overconfident individuals. When leaders don't show any signs of expertise, then followers use their unwarranted faith for proof of their abilities. Furthermore, toxic narcissists tend to show off their inflated sense of self-confidence. Increased output and less stress are the results of giving workers more freedom and responsibility on the job. Toxic leaders would not only tolerate poor conduct but would also reward incompetence repeatedly. Their haughtiness belies their prejudices and biases, which manifest as sexism, racism, and other types of bigotry.⁸⁹ The phenomenon of toxic leadership is becoming more and more widespread in the management literature, and it has intrigued a great deal of scholars in recent years.⁹⁰ Recent studies have looked into the negative aspects of leadership and the effects that toxic leadership has on the mental health of employees and the success of businesses.⁹¹ Toxic leadership is a major component of shadowy leadership, and it is similar to a poison in that it can spread covertly and unnoticed. Toxic leadership not only taints individuals, but it also has an effect on groups, and ultimately, the entire organization.⁹² A list of some of the telltale signs of toxic leaders has been shown below.

Arrogance. Leaders who are toxic often exhibit an inflated sense of self-importance and hubris. Because of their inflated sense of self-importance, they are ostentatious and full of themselves. They have a tendency to insist that everyone else see things their way. Particularly when it originates from underneath them, this type of person will not tolerate criticism. Furthermore, they show zero regard for their teammates and are unwilling to lend a hand to anybody in need. They have a tendency to view their staff as second-class citizens and expect them to silently follow their every command.⁹³ As a general rule, arrogance is merely the appearance of confidence; it becomes problematic when leaders pretend to be capable of handling everything that is thrown at them when, in fact, they are not. As a

⁸⁷<https://www.masterclass.com/articles/toxic-leadership>, accessed on 11 Jan 2026

⁸⁸ <https://aboutleaders.com/self-evaluation-6-signs-youre-a-toxic-leader/>, accessed on 08 Oct 2023

⁸⁹ Ashforth Blake, (1994), "Petty Tyranny in Organizations", *Human Relations*, 47 (7): 755–778, accessed on 11 Jan 2026

⁹⁰ Labrague LJ, Lorica J, Nwafor CE, Cummings GG. Predictors of toxic leadership behaviour among nurse managers: A cross-sectional study. *J Nurs Manag*. 2021;29(2):165-176. doi:10.1111/jonm.13130, accessed on 11 Jan 2026

⁹¹ Gallus JA, Walsh BM, van Driel M, Gouge MC, Antolic E. Intolerable Cruelty: A Multilevel Examination of the Impact of Toxic Leadership on U.S. Military Units and Service Members. *Military Psychology*. 2013;25(6):588-601. doi:10.1037/mil0000022, accessed on 11 Jan 2026

⁹² Bhandarker A, Rai S. Toxic Leadership: Emotional Distress and Coping Strategy. *IJOTB*. 2019;22(1):65-78. doi:10.1108/ijotb-03-2018-0027, accessed on 11 Jan 2026

⁹³<https://aboutleaders.com/mindfulness/>, accessed on 11 Jan 2026

result, others around them withdraw, and the real problems remain dormant.⁹⁴Toxic leaders are incredibly haughty and full of themselves. They believe they are right more often than not and take what they say at face value. No one can count on them for assistance, and they take offense at the slightest hint of criticism, particularly from those lower in the organization.

Autocratic. Toxic bosses actively discourage employees from voicing any viewpoints other than their own. They take it for granted that everyone else would subtly comply with their directives. A toxic boss acts more like a king or top dog than an actual boss because of their inflated sense of self-importance. Workers are merely pawns, lower-class creatures whose sole purpose is to carry out the leader's commands.

Irritable. Toxic leaders also seem extremely irritable, which is probably not unexpected. They would rather not be interrupted for anything. Because they refuse to consider other people's perspectives, they hate being interrogated and try to avoid it at all costs. The absence of fresh, unfettered thinking under a toxic leader causes the organization to stagnate.

Maladjusted. A poisonous boss's stern and haughty exterior bely an immature child who is terrified of change. They have a hard time adapting to new situations and are quite rigid. If there are any organizational changes, the toxic boss will most certainly be the one to fight them fiercely.

Lack of confidence. An angry, immature youngster who is terrified of change lurks beneath a poisonous boss's haughty, pompous exterior. They are extremely resistant to change and have a hard time adjusting. A toxic boss is someone who will fight tooth and nail to prevent the company from making any changes.

Incompetent. Even the most basic decisions or jobs can be a battle for a toxic leader, who may believe they are the best despite their incompetence. The only way they feel valued and important is when they put other people down and criticize them.

Hierarchical. Toxic leadership will eventually collapse in the absence of a strict chain of command. The weight of the corporate hierarchy is a common source of stress for a toxic CEO. Toxic leaders are masters at imposing their will on subordinates through the use of seniority and rank.

Unrealistic expectations. Leaders with a toxic personality type are known to establish goals that are unreasonable and unattainable. Demoralization sets in when team members see their goals as impossible to reach. The corporation is doomed to fail as the workload mounts.

Symbols of personal authority. These symbols include priority access to parking, full ability to re-source, and possibly displaying their portraits and achievements throughout the workplace.

Discriminatory. As expected, toxic leaders frequently exhibit discriminating behavior. They frequently act discriminatorily based on their preconceptions and prejudices, which can take the form of sexism, racism, or ageism.⁹⁵

Lack of Empathy. A toxic and unwelcoming work atmosphere is the result of executives who do not demonstrate empathy towards their employees.⁹⁶ Disregarding employees' worries and lives outside of work are two examples of how a lack of empathy can show itself. Leaders who are toxic to their teams cause more tension, dissatisfaction, and burnout by putting their own agenda ahead of their employees' health and happiness. Toxic leadership can be countered when leaders cultivate and demonstrate empathy. Leaders may cultivate a constructive and efficient work atmosphere by comprehending and appreciating the feelings and life experiences of their employees.

Excessive Micromanagement. There is a direct correlation between executives that micromanage their teams and a decline in trust, autonomy, and innovation. When micromanagers doubt their employees, morale and productivity take a nosedive. Not only does this poisonous behavior stunt personal development, but it also makes it harder for the team to work together and come up with new ideas.

Defensiveness and Ego Centricity. A culture of fear and silence is fostered when leaders exhibit protective behavior, such as refusing to accept criticism or acknowledge their shortcomings. A lack of teamwork and fresh ideas is inevitable under egocentric leaders since they put themselves first. Employee morale and trust are both lowered by this toxic behavior. Leaders should prioritize self-reflection and humility to combat toxic leadership. Fostering a supportive and growth-oriented work atmosphere can be achieved by leaders who are open to feedback, who admit when they're wrong, and who put the requirements of the team above them.

Inconsistent Communication. When team leaders fail to communicate clearly and consistently, it causes confusion and misalignment.⁹⁷ A lack of openness can breed gossip, mistrust, and limit productivity. When proper communication is inconsistent, the team members are often left uninformed, struggling to grasp their roles and expectations fully. Toxic leaders can suppress critical information, engage in selective reporting, or alter their positions without providing explanations. To counteract toxic leadership, leaders need to give priority to clear and efficient communication. An open-door policy, regular updates, and explicit expectations can significantly enhance transparency, collaboration, and contribute to a healthier work environment.

Favoritism and Unfair Treatment. Leaders breed animosity and poison in the workplace when they

⁹⁴Karthikeyan, Dr C., (2017), "An Exploratory Study On TOXIC Leadership and Its Impact on Organisation; A Leadership Perspective", International Journal of Research in Social Sciences, 7 (3) – via Academia.edu, accessed on 11 Jan 2026

⁹⁵<https://yscouts.com/10-toxic-leadership-characteristics/>, accessed on 11 Jan 2026

⁹⁶<https://www.linkedin.com/pulse/what-happens-when-leader-manager-lacks-empathy-kingsley-dibie/>, accessed on 11 Jan 2026

⁹⁷<https://www.entrepreneur.com/leadership/7-leadership-communication-mistakes-that-could-destroy-your/435685>, accessed on 11 Jan 2026

exhibit partiality to certain employees or groups. This kind of conduct ruins team spirit and morale by undermining principles of equity, impartiality, and justice. A toxic work environment is one in which some employees are often rewarded while others are left to fend for themselves. Fairness and equity must be leaders' top priorities if toxic leadership is to be addressed. They need to make sure that everyone is treated fairly and has access to the same resources. Leaders may encourage development and output by creating an environment where everyone feels welcome and valued.

High Employee Turnover Rate. Workers get irritated, disgruntled, and unmotivated when leaders foster a negative work atmosphere. The revolving door of talent is a direct outcome of this poisonous culture, which causes brilliant people to seek chances elsewhere. A company's stability, production, and reputation are all negatively affected by high turnover rates. Toxic leaders either deny or downplay their responsibility for this turnover. Leaders can combat toxic leadership by making employee happiness, fulfillment, and advancement their top priorities. In order to keep their best employees from leaving, executives should foster an encouraging and rewarding workplace.

Resistance to Change. Business development, creativity, and flexibility are impeded when top executives fight or obstruct changes that are essential for the company. Because they are afraid that change may undermine their authority or control, toxic leaders frequently cling to outdated practices. A stale and outmoded work environment is the result of this opposition. It blocks innovation, stifles advancement, and annoys workers who are hoping for a change for the better. Toxic leadership can be countered when leaders are open to change and promote a mindset of constant improvement.⁹⁸ Leaders may encourage creativity, boost output, and cultivate an optimistic and progressive work environment by stressing the importance of being able to roll with the punches.

Lack of Vision or Clear Direction. Employees get confused and unsure of what the organization's purpose is when leaders do a poor job of communicating it. Workers lose focus and enthusiasm since they aren't sure what they're working toward. In their haste to advance their own interests or achieve immediate success, toxic leaders may fail to chart a course for the future. Toxic leadership can be overcome if leaders set and convey a clear vision for the future of their team. Leaders motivate their teams to work together toward common objectives and achieve success by outlining a path forward.

Not leading by example. When leaders don't back their words with actions, it damages their reputation and causes team members to lose faith in them. A toxic boss is one who lacks professionalism, honesty, and accountability while also expecting too much from their people.⁹⁹ Team members become resentful, disrespectful, and unmotivated as a result of this hypocritical behavior. Toxic leadership can be combated if leaders provide a good example. Trust, a healthy work environment, and employee dedication can be achieved when leaders set an example of the values, behaviors, and work ethic they like to see from their teams.

Suppressing Feedback and Avoiding Accountability. Leadership hinders development, innovation, and teamwork when it forbids or ignores suggestions for improvement from subordinates.¹⁰⁰ Overall success is brought about by the proper work environment. The flip side is that problems that arise from a poisonous work environment might be the final straw that breaks the camel's back of any company. Interestingly, it's not always easy to see the big picture when you're in the thick of things at work. In a similar vein, leaders don't always see when things are starting to go awry. The members of the Forbes Business Council have agreed on a set of signs that company executives should keep an eye out for in order to foster a safe and healthy work environment.¹⁰¹

Poor Communication. A poisonous work environment is typically the result of a lack of communication between management and staff. On a quarterly basis, leaders may call a meeting where all members have an opportunity to voice their opinions on the current state of affairs. It was a tremendous success after a while of getting underway and gaining confidence.¹⁰² It drives disengagement, fear, and high turnover by creating unclear expectations, one-way messaging, and inconsistent directives. Toxic leaders often withhold information, avoid necessary feedback, or use communication to intimidate, resulting in low morale and severe distrust. In a recent survey, 76% of employees cited the C-suite as having the greatest impact on culture. Colin D. Ellis explores five of the traits that toxic leaders display.¹⁰³

Fear of Speaking Up. In a poisonous workplace, people are afraid to speak out for fear of retaliation. Leaders should keep in mind that they are human and that mistakes are inevitable. Toxic effects can be lessened if problems are detected sooner.¹⁰⁴ Moreover, leaders ought to request particular feedback. Employees are afraid of facing retaliation and hostility if they speak up. They worry about upsetting their managers or leaving a coworker feeling betrayed. Most feel

⁹⁸ John AG, Francis AI, Chukwu II. Improving Sales Performance through Sales Force Motivation Strategies: A Study of Pharmaceutical Firms in Nigeria. *IntJBussMgtEcoRes*. 3(5):1-15, accessed on 13 Jan 2026

⁹⁹<https://awarerecruiter.com/hyper-competitive-workplace-culture/>, accessed on 13 Jan 2026

¹⁰⁰<https://awarerecruiter.com/toxic-leadership/>, accessed on 13 Jan 2026

¹⁰¹<https://www.forbes.com/sites/forbesbusinesscouncil/2023/05/31/17-symptoms-of-a-toxic-workplace-leaders-should-watch-for/> accessed on 13 Jan 2026

¹⁰² Fahie D. The Lived Experience of Toxic Leadership in Irish Higher Education. *IJWHM*. 2019;13(3):341-355. doi:10.1108/ijwhm-07-2019-0096, accessed on 13 Jan 2026

¹⁰³ <https://executivepa.com/five-characteristics-of-a-toxic-leader/>, accessed on 13 Jan 2026

¹⁰⁴ Morrison, E. W. (2014). Employee Voice and Silence. *Annual Review of Organizational Psychology and Organizational Behavior* 1, 173-197, accessed on 31 Jan 2026

that their career opportunities will deeply suffer if they voice their concerns.¹⁰⁵

Selfish Goals. It involves a consistent pattern of prioritizing personal gain, power, or recognition over the well-being of the team and the organization's goals. These leaders often operate under a "me, I, and myself" syndrome, using their authority to satisfy their own agenda.¹⁰⁶ Those in charge should examine them thoroughly first. There is a clear distinction between a boss and a leader when it comes to creating or enabling a poisonous work environment. If upper-level management isn't concerned about the emotional well-being and intrinsic drive of their employees, that should raise red flags.

Mental Health Decline. It causes severe mental health decline, manifesting as chronic stress, anxiety, burnout, depression, and low self-esteem due to bullying, humiliation, and unpredictable behavior. This hostile environment erodes employee well-being, leading to emotional exhaustion, disengagement, and often, high staff turnover.¹⁰⁷ 'A decline in the mental health of their people' is a red flag that leaders should be aware of. Fifty percent or more of employees feel their job focus has shifted in the past year, according to a recent survey in a business organization. Many global employees rank their mental health as their top priority, according to one survey. To that end, top-level management should think about ways to improve the mental health of their staff.

Disengagement. Refraining from actively participating in or being a part of anything is what we mean when we talk about disengagement. There is typically an underlying problem that becomes the driver or park of workflow and productivity within the team when there is a reduction in enthusiasm or passion for job obligations. Find the poison and eliminate it immediately.¹⁰⁸

High Turnover Rate. The high employee turnover rate is one sign that management should be on the lookout for in a hazardous workplace. Frequent employee turnover could be a sign of problems like unhelpful management, an absence of resources, or an unpleasant work environment. To tackle this, leaders should promote open communication, provide avenues for anonymous input, and aggressively work to identify and address the problem's underlying causes.¹⁰⁹

Constant Team Conflict. Constant fighting inside the team is a glaring indication that leaders are dealing with a poisonous environment. When team

members are no longer able to freely and honestly discuss the issues that are bothering them, will conflict in the workplace. Passive aggression results from letting bitterness simmer under the surface. Then, it fosters the ideal environment for poison to flourish. Constant fighting inside the team is a glaring indication that leaders are dealing with a poisonous environment.¹¹⁰

Gossip. In the break room, gossip can be extremely harmful. It frequently happens because someone on the team is not thrilled with another member. Instead, confronting the other person openly about their problem, they will rather whisper behind their back.¹¹¹ A person's dissatisfaction with another team member is frequently the cause. They would rather murmur behind their backs than face the other person directly about their problem.¹¹²

Hyper-Competitiveness. One sign of a toxic workplace is excessive competition, which frequently reflects a lack of teamwork and conflict among coworkers. It is an indication that leadership is not effectively fostering a cooperative and cohesive work atmosphere if staff members feel that they are always competing with one another.¹¹³

Lack of Collaboration and Communication. Lack of cooperation and candid communication is one sign of a hazardous workplace. Employees become disengaged and reluctant to take chances or speak up when they don't feel comfortable sharing their thoughts or worries. Therefore, leaders need to be on the lookout for indications of low morale and decreased production due to fear-based decision making and closed mind-sets.¹¹⁴

Chronic Complainers. Leaders need to pay attention to employees who constantly complain at work. By spreading negativity, lowering morale, and decreasing productivity, they can harm the company. By rejecting contributions and solutions, these workers impede growth, damage the company's brand, and foster a toxic work environment.¹¹⁵

Quiet Quitting. Leaders need to be aware that silent resignation is one sign of a hostile workplace. As a result, workers perform the bare minimum, become disengaged with the company's principles, stop voicing their thoughts, and lack enthusiasm for their work. A team's culture is detrimental if its members aren't taking

¹⁰⁵ <https://ethicalleadership.nd.edu/thought-leadership/create-a-speak-up-culture>, accessed on 13 Jan 2026

¹⁰⁶ <https://pmc.ncbi.nlm.nih.gov/articles/PMC8238029/>, accessed on 31 Jan 2026

¹⁰⁷ Bhandarker A, Rai S. Toxic Leadership: Emotional Distress and Coping Strategy. *IJOTB*. 2019;22(1):65-78. doi:10.1108/ijotb-03-2018-0027, accessed on 31 Jan 2026

¹⁰⁸ <https://www.forbes.com/sites/forbesbusinesscouncil/2023/10/17/20-ways-top-companies-cultivate-thriving-communities/?sh=42f2b1dd19e3>, accessed on 13 Jan 2026

¹⁰⁹ <https://councils.forbes.com/profile/Andrei-Neacsu-CTO-HyperSense-Software-Inc/6d74dd83-55cd-45ea-81c7-b66c2467e41f>, accessed on 13 Jan 2026

¹¹⁰ <https://councils.forbes.com/profile/Erik-Pham-Founder-CEO-Health-Canal/962f18ee-2a8c-41b8-aa9d-fa1d142bc0f0>, accessed on 13 Jan 2026

¹¹¹ <https://www.tiberhealth.com/>, accessed on 25 Jan 2026

¹¹² <https://www.forbes.com/sites/forbesbusinesscouncil/2023/05/31/17-symptoms-of-a-toxic-workplace-leaders-should-watch-for/?sh=474d797e50b0>, accessed on 25 Jan 2026

¹¹³ <https://thompsonexterior.com/>, accessed on 17 Oct 2023

¹¹⁴ <https://councils.forbes.com/profile/Tomas-Keenan-Founder-Step-It-Up-Academy/29bcaff8-02cb-485b-8868-d3ae250f25af>, accessed on 25 Jan 2026

¹¹⁵ <https://www.setschedule.com/>, accessed on 13 Jan 2026

initiative, solving challenges, and aiming for excellence.¹¹⁶

Low Morale. Low employee morale is a symptom of a poisonous workplace culture that leaders need to be aware of. Ignoring such risks might result in decreased production, lost talent, and a further decline in team morale. To find and address the core of the issue, leaders must promote open communication and include staff members. Long-term success and employee satisfaction are the results of investing in a positive workplace culture.¹¹⁷

No Desire to Take Risks. When there is little motivation to take measured risks, a poisonous culture may develop. This frequently occurs when the company's founder leaves or when corporate bullies go unpunished. Even if a risk doesn't work out, it should still be praised and supported. Bullying can be prevented and all employees' opinions heard through a 360-degree evaluation procedure.¹¹⁸

Contempt. Lack of motivation to take measured risks might lead to the emergence of a poisonous culture. This frequently occurs when corporate bullies go unpunished or when the founder leaves the company. It is important to support and celebrate taking chances, even if they don't work out. A 360-degree evaluation procedure can guarantee that bullying is controlled and that all employees' opinions are heard.¹¹⁹

Lack of Zeal. One sign of a toxic workplace is a lack of enthusiasm among employees. This may occur when workers believe they are not following a clear plan or direction. Employees exhibit the least interest in their work when they are unsure of their goals or when they are aware that they will not be realized, and they will leave when they are given a more fulfilling task.¹²⁰

Self-Servitude. Toxic heads are egocentric. They frequently manipulate and manage their team, making them feel the weight of corporate authority. This individual is very good at utilizing their position or seniority to further their own interests and personal desires within the firm. For their own benefit, they frequently offer misleading recommendations or counsel.¹²¹ An approach to leadership that prioritizes serving others rather than being served enhances performance and fosters a harmonic flow. Leadership that promotes a

healthy work environment fosters trust, which in turn increases engagement and output.

Lack of Faith and Confidence. Everyone would agree that the worst kind of boss or supervisor is the one who watches over their every step on every job.¹²² On top of making a leader feel inadequate, having an extra set of eyes and ears constantly evaluating his every move is an uncomfortable experience.¹²³ Lack of faith in workers' talents is a hallmark of toxic leadership. They fail to take context into account while making decisions, which severely restricts the employee's room for innovation and flexibility. Such an attitude may stunt members' personal and team development.¹²⁴

Incompetence. Workers have an innate ability to discern whether their boss lacks the decision-making skills necessary to keep them in their place. To satisfy their egos, toxic leaders often diminish the value of their employees by constantly critiquing their work.¹²⁵ Beneath their polished exterior lies a startling truth: their incompetence runs deep, and they often struggle with even the simplest decisions.¹²⁶ This leadership style often leads to poor communication. When decision-making and communication skills are weak, leadership can quickly fail. Consequently, these leaders tend to surround themselves with a close-knit group of supporters who share their views. This "yes" group typically mirrors the leader's behavior, making them less receptive to innovative ideas from employees.

Unmotivated and Lacking Support. A leader's lack of support is another thing that deters individuals. In addition to impeding employees' growth, a disinterested manager limits their capacity to meet the goals of the company.¹²⁷ Such bosses are self-centered, never give credit where it is due, and are unable to recognize the efforts of their employees. Ego and fear are the root causes of this conduct. Moreover, when workers aren't inspired to do their best, then their passion for the goal wanes and which in turn causes projects to run behind schedule and, ultimately, the company to fail.¹²⁸

Lack of Moral Compass. Nevertheless, we are living in a world that advocates emotional intelligence and leading with empathy, there remain many toxic leaders who are solely out for themselves and who do great harm to their workplaces without regard for the consequences. When things get dark, leaders should be

¹¹⁶<https://councils.forbes.com/profile/Kent-Ingle-President-Southeastern-University/183a4793-ef1b-4b78-9f8e-b5b2a0a686cd>, accessed on 25 Jan 2026

¹¹⁷<https://www.paymentpilot.com/>, accessed on 25 Jan 2026

¹¹⁸<https://councils.forbes.com/profile/Chris-Haroun-Founder-CEO-Haroun-Education-Ventures-Inc/d51b0650-282c-4bd4-9cd9-408c7ccf64b9>, accessed on 17 Oct 2023

¹¹⁹ <https://zain-ventures.com/>, accessed on 25 Jan 2026

¹²⁰<https://globalsquirrels.com/>, accessed on 25 Jan 2026

¹²¹S Alexander Haslam, (2004), *Psychology in Organizations*, SAGE.p. 142, ISBN 978-0-7619-4231-3, accessed on 11 Jan 2026

¹²²<https://aboutleaders.com/styles-of-leadership-in-management/>, accessed on 08 Oct 2023

¹²³Ronald E. Rice; Stephen D. Cooper (2010). *Organizations and Unusual Routines: A Systems Analysis of Dysfunctional Feedback Processes*. Cambridge University

Press.p. 287. ISBN 978-0-521-76864-1, accessed on 11 Jan 2026

¹²⁴Peyton, Pauline Rennie (2003). *Dignity at Work: Eliminate Bullying and Create a Positive Working Environment*. ISBN 9781583912386, accessed on 11 Jan 2026

¹²⁵<https://sushmitapedaprolu.medium.com/boost-peoples-confidence-not-their-ego-31d186c62c84>, accessed on 11 Jan 2026

¹²⁶Rayner,et al, (1997), "A Summary Review of Literature Relating to Workplace Bullying", *Journal of Community and Applied Social Psychology*, 7 (3): 181–191, accessed on 11 Jan 2026

¹²⁷ <https://www.liveabout.com/the-toxic-boss-syndrome-2275152>, accessed on 11 Jan 2026

¹²⁸Kellerman, Barbara (2004) *Bad Leadership: What It Is, How It Happens, Why It Matters* Boston, Massachusetts: Harvard Business Review Press. ISBN 9781591391661, accessed on 11 Jan 2026

able to look to their moral compass for guidance.¹²⁹ In times of difficulty, they should be empathetic, fair, and compassionate. The pursuit of fame and fortune, however, often takes precedence over these principles.¹³⁰ It involves leaders prioritizing self-interest, ego, and power over ethical principles, fairness, and the well-being of their followers. These leaders often demonstrate dishonesty, hypocrisy, and a lack of empathy, creating destructive environments that drive high employee turnover and damage organizational culture.

IV. Leadership Challenges in 21st Century

The 21st century has been marked by disruption, ongoing change, and technological breakthroughs, profoundly affecting how people live and work. Key events like the dot-com boom, the rise of smartphones, digital platforms, social media, and emerging technologies such as IoT, 5G/6G, AI, robotics, machine learning, and blockchain have reshaped global business and organizational functions. These advancements have democratized information, fostering a more seamless and efficient global economy. The rapid growth of emerging economies like China, India, Brazil, Indonesia, and Middle East nations has shifted the economic landscape, altering leadership dynamics. Today's leaders must navigate a complex, evolving environment, managing change proactively for long-term success growth.¹³¹ Kodak exemplifies a company that lost its market position due to leadership's failure to adapt to competition and changing circumstances. Once the most significant film producer, Kodak's management hesitated to embrace digital technology, fearing it would harm their film business. This reluctance contributed to their decline and layoffs as demand for film plummeted. Similarly, companies like Blockbuster, Pets.com, and Nokia struggled because they failed to adapt to market changes. Effective leadership is now more critical than ever, as shifts in needs and motivations demand new strategic approaches. The future can no longer be predicted with any exactness and this makes the international business environment more uncertain than it has been ever before. So, challenges are multifaceted and few single causes or solutions present themselves. This makes the international business environment arguably more complex than it has been.¹³² In an increasingly consistent and rapidly changing world, the nature of leadership is undergoing a profound transformation. Leaders today must navigate a

complex landscape characterized by technological advancements, economic uncertainties, geopolitical shifts, and social changes. These global dynamics present both challenges and opportunities for future leaders.¹³³

As the world becomes more volatile, uncertain, complex, and ambiguous (VUCA), leaders must adapt to new paradigms, develop innovative strategies, and cultivate a diverse range of skills to guide their organizations and societies effectively.¹³⁴ Despite the challenges, global dynamics also present numerous opportunities for future leaders. Technological advancements can drive innovation, improve efficiency, and create new business models. Leaders who can harness the power of big data, AI, ML, IoT, and digital tools can gain a competitive edge and drive organizational success. Economic uncertainties, while challenging, also create opportunities for strategic thinking, innovation, and growth. Leaders who can navigate these complexities can identify new markets, optimize operations, and create value. Geopolitical shifts can open up new opportunities for collaboration, partnerships, and expansion into new regions.¹³⁵

Again, there is very little clarity on what specific events mean and the effects they might have in the short, medium and long-term. So, a good leader cares about others; a leader must lead others to success. If a leader's goal was to achieve success only for one's own self, then I'd call him or her a climber, for one who climbs to success, but not a leader. A leader who does not benefit others serves no purpose in an organization or in society. The future leaders are becoming aware of their corporate social responsibilities thereby expressing concern for the environment, human rights, community development and employee well-being.¹³⁶ Future leaders must have in-depth and updated understanding of CSR and its application; be able to understand community needs, and be able to assess the impact of their business on the community. The challenges faced by 21st century leaders are increasingly significant.

Geopolitical volatility: Organizations may suffer abrupt yet catastrophic harm due to geopolitical factors. Financial assets can be depleted and capital investments chased away by unstable geopolitical settings. Stricter government controls in local markets may result from high geopolitical volatility, making it more

¹²⁹ <https://www.linkedin.com/pulse/importance-frontline-leadership-bill-george-30kwc>, accessed on 17 Jan 2026

¹³⁰ Lipman-Blumen Jean, (2006) *The Allure of Toxic Leaders: Why We Follow Destructive Bosses and Corrupt Politicians—and How We Can Survive Them* Oxford University Press. ISBN 9780195312003, accessed on 17 Jan 2026

¹³¹ <https://martinroll.com/resources/articles/leadership/leadership-in-the-21st-century/>, accessed on 25 Jan 2026

¹³² Kim, W.K. and R.A. Maubourgne (1992). "Parables of Leadership", *Harvard Business Review*, (July-August) □ 123, accessed on 25 Jan 2026

¹³³ Hashimy, S. Q., Jahromi, A., Hamza, M., Naaz, I., Nyamwero, N. B., & HT, B. (2023). *Nurturing Leadership and Capacity Building for Success: Empowering Growth*. *International Journal of Rehabilitation & Special Education*, 3(2), accessed on 29 Jan 2026

¹³⁴ Anwari, A., & Suzianti, A. (2024). Mapping future competencies: a comprehensive review of organizational challenges, competencies, and strategies to survive and compete in the digital era. *Journal of Syntax Literate*, 9(3), accessed on 29 Jan 2026

¹³⁵ Figueiredo, P. C. N., Sousa, M. J., & Tomé, E. (2023). Integrative model of the leader competences. *European Journal of Training and Development*, 47(5/6), 533-564, accessed on 29 Jan 2026

¹³⁶ Avoli, B. and B.M. Bass (1988). "Transformational Leadership, Charisma and Beyond", in J.G. Hunt, H.P. Baliga, H.P. Dachler and C.A. Schriesheim (eds.), *Merging Leadership Vistas*. Lexington, MA □ LezingtonBooks, accessed on 25 Jan 2026

expensive for businesses to operate in particular regions, given that the majority of the factors—such as governments, laws, the environment, trade, labor markets, etc. Despite remaining beyond their control, geopolitical risks have grown to be a significant concern for leadership teams. Geopolitical conflict (like Russia-Ukraine war, Iran-Israel conflict, etc.) is amplifying existing pressures as rising energy costs, persistent inflation, and slowing growth collide with skepticism about technology spending, particularly large AI investments. This is forcing hard choices about which platforms and AI investments truly matter. As tech leaders look to defend their AI investments, they'll need to move beyond experimentation and small-scale productivity gains to enterprise-wide strategies that deliver measurable outcomes.¹³⁷ That means prioritizing high-value use cases, scaling agentic AI for future use cases, and embedding responsible AI governance. As conflict increasingly plays out across physical, digital, and cyber domains simultaneously, technology leaders must assume disruption rather than plan for stability. Cyber activity is rising alongside kinetic conflict, as evidenced by the recent attack on the Fortune 500 medical technology firm Stryker by an Iranian hacker group.¹³⁸ While banking, defense, manufacturing, government, and critical infrastructure are obvious targets.

Technological disruptions: In 21st century, technology advances at a breakneck pace. Today, across industries, from AI, to biotech, to neuroscience, space exploration, and sustainability, we're working to build systems and machines that help us do what we do, but better. It gives innovation and progress, but also the complex, interwoven relationship between technology and humanity. Technological disruptions define the twenty-first century, becoming increasingly common across sectors like manufacturing, technology, and healthcare. Data mining companies are building DNA databases, while 3D printers are transforming production of everyday items, construction, and artificial organs. AI combined with cloud computing expands data-driven decision-making. These advances challenge norms and drive entrepreneurship, with startups disrupting traditional models by innovating and marketing new products, shaping future markets. Successfully navigating a changing landscape requires balance. Leaders need to avoid the 'early bird' syndrome of leaping before they look while also understanding the value of purposeful transformation. This becomes a matter of risk management versus fear of failure and over-eagerness versus procrastination. Leaders need to clarify their businesses and team's needs, then weigh them against the new technology's proposed benefits to strike a conversant balance and sustainability.¹³⁹

Economic and political uncertainty: Organizations must deal with political and economic unpredictability after removing geopolitical concerns at the national level. Every firm, regardless of size, wants to function in politically and economically secure circumstances. Revenues, profits, and investments can be severely harmed by national environments that are marked by recurrent labor strikes, social upheaval, and turmoil. Managing political and economic unpredictability has emerged as a crucial leadership challenge in the twenty-first century. Economic and political uncertainties must be taken into consideration in any growth strategy since businesses are looking to expand and startups are looking to scale up more quickly. Leaders are encouraged to adopt flexible and innovative leadership strategies that respond effectively to global dynamics. The insights on resilience and crisis management also guide managers in preparing for and addressing potential disruptions, thereby improving organizational agility and competitiveness. Global dynamics requires a strategic blend of adaptability, foresight, and ethical stewardship, where understanding the impact of economic, political, social, technological, and environmental factors becomes essential for global leadership success.¹⁴⁰

Shifting demographics: It is among the most significant leadership challenges of the 21st century, profoundly altering economic and social landscapes. Leaders are navigating aging populations, declining birth rates in developed nations, and increasing workforce diversity, which require a shift in strategy, inclusion, and intergenerational management. Overall, there have been major changes in the global population. There are more single-parent and dual-income households, an aging population that requires more health and social services, and a more diverse workforce. These demographic changes cause constant shifts in the demand for a company's goods and services. This means companies must keep their product lines current.¹⁴¹ Corporate leaders face the challenge of finding a sustainable way to generate profits while anticipating and adapting to upcoming demographic shifts.

Having a balanced short-term and long-term lens. Businesses face pressure to prioritize short-term financial success, driven by demands from shareholders and analysts for quarterly results. Yet, long-term plans that involve careful resource allocation are crucial for sustained success. The tension between short-term gains and long-term strategies creates ambiguity and risks, making it vital for leadership to find a strategic balance. This balance helps address immediate challenges like labor strikes and unrest, as well as medium- and long-term concerns such as geopolitical issues. Modern leaders must balance long-term growth

¹³⁷ <https://www.forrester.com/blogs/geopolitical-volatility-has-become-a-technology-leadership-test/#>, accessed on 25 Jan 2026

¹³⁸ <https://www.forrester.com/blogs/the-stryker-attack-enterprise-resiliency-plans-cant-ignore-uem>, accessed on 25 Jan 2026

¹³⁹ <https://www.inc.com/inc-masters/leadership-in-times-of-technological-disruption.html>, accessed on 29 Jan 2026

¹⁴⁰ Al-Surmi, A., Bashiri, M., & Koliousis, I. (2022). AI based decision making: combining strategies to improve operational performance. *International Journal of Production Research*, 60(14), 4464-4486, accessed on 29 Jan 2026

¹⁴¹ The World Economic Forum Gender Gap Index 2007 Confederation of Indian Industries Report, accessed on 29 Jan 2026

with stakeholder expectations to strengthen the company's brand and ensure resilience rewards.

Resilience: Organizations face growing pressure to prioritize short-term business wins over long-term strategies. Companies often adopt a short-term outlook because they must report quarterly earnings and profits to satisfy investors and financial analysts. However, long-term initiatives that require organizational resources and careful planning are essential for sustained success today. The ongoing conflict between short-term and long-term goals adds more uncertainty and risk to decisions about capital spending and resource distribution. In this century, effective leadership requires a strategic balance between immediate corporate aims and long-term ambitions. It's crucial to manage conflicting forces, like labor strikes, civil unrest, and competitor imitation, which have short-term impacts, alongside those impacting medium- and long-term outcomes, such as geopolitical shifts.¹⁴² Leaders today need to find ways to meet stakeholders' demands for instant benefits while also investing in long-term objectives that will grow and strengthen the organization reputation.

Having a horizontal and vertical outlook: The concept of "horizontal leadership" refers to inspiring groups of individuals to collaborate towards a common goal. In contrast, a top-down, military-style approach exemplifies vertical leadership, which is fundamentally the opposite. Effective leadership resides in the balance between these two opposing philosophies. Various factors, such as organizational structures, the cultural diversity of employees, global presence, command-and-control frameworks, and the influence of local entities, all shape contemporary leadership styles. Today's effective leadership philosophies tend to emphasize granting teams greater autonomy and responsibility, as our world becomes more interconnected and flatter.¹⁴³ Leadership teams should actively listen, encourage the sharing of information and opinions, and foster a trusting environment within a landscape characterized by collaboration, communities, and networks. While vertical leadership offers a different approach, it remains valuable for helping teams resolve conflicts, make decisions in complex situations, provide guidance during uncertainty, and lead with courage, empathy, and conviction.

Global perspectives and local insights: Motivating groups of people to support and accomplish a common objective is known as horizontal leadership. Vertical leadership, on the other hand, is the exact antithesis of top-down, military-style commanding teams. There is a middle ground between these two diametrically opposed leadership philosophies. In the modern

world, command-and-control systems, worldwide presence, cultural diversity of employees, organizational structures, and the involvement of local entities all influence leadership styles. Giving teams greater ownership and responsibility is becoming a common trend in effective leadership styles as the world gets flatter and more interconnected. In a world of networks, communities, and cooperation, Leadership teams should listen attentively, encourage the exchange of information and opinions, and foster a climate of trust.¹⁴⁴ While the vertical leadership style is also significant, it manifests in a distinct way. This approach involves making decisions in ambiguous situations, helping teams navigate conflicts, offering guidance during uncertain periods, and leading with courage, empathy, and conviction.

Strong strategic compass: Executive teams and executives must have a strong strategic compass in the 21st century. In addition to having a good sense of self-awareness, outstanding leaders must be passionate visionaries with a clear sense of purpose and direction when leading their teams. Importantly, their personal vision should be entirely consistent with the organizations. But in these uncertain times, a leader's operational plan should be flexible. While making progress toward long-term organizational goals is important, a leader should be willing to explore and embrace different approaches to reach these objectives. Leaders should remain unwavering despite severe disturbance and mayhem, much like a compass that always points north. Contemporary leaders need to develop cultural intelligence to navigate the intricacies of a globalized workforce. It involves understanding and appreciating different cultural norms, fostering an inclusive environment, and leveraging diverse perspectives for creative problem-solving. Investing in cross-cultural training for leaders and employees can promote effective communication and collaboration. The COVID-19 pandemic enhanced the adoption of remote work, ushering in a new era of flexibility in work arrangements. Contemporary leaders must now grapple with the challenges of leading remote or hybrid teams, maintaining productivity, and ensuring the well-being of employees in virtual work environments.¹⁴⁵

Globalization: It describes the phenomenon as growing interdependence of the world's economies, cultures, and populations, brought about by cross-border trade in goods and services, technology, and flows of investment, people, and information. However, the countries have built economic partnerships to facilitate these movements over many centuries. The term gained popularity after the Cold War in the early 1990s, as these cooperative arrangements shaped contemporary everyday life. The wide-ranging effects of globaliza-

¹⁴² Longenecker, C. O., & Wittmer, J. (2024). CEO reflections on leadership lessons from the global pandemic: back to basics during crisis. *Leadership & Organization Development Journal*, accessed on 25 Jan 2026

¹⁴³ McKenzie, C., Brophy, K., Konstanta, G., & Webster, L. (2023). A vision for change leadership: Trust, transparency and accountability at University of Wollongong Library. *The Journal of Academic Librarianship*, 49(3), 102710, accessed on 25 Jan 2026

¹⁴⁴ Mosteanu, N. R. (2024). Adapting to the Unpredictable: Building Resilience for Business Continuity in an Ever-Changing Landscape. *European Journal of Theoretical and Applied Sciences*, 2(1), 444-457, accessed on 25 Jan 2026

¹⁴⁵ Woodhill, J., & Millican, J. (2023). *Systems Thinking and Practice: A guide to concepts, principles and tools for FCDO and partners*, accessed on 25 Jan 2026

tion are complex and controversial. As with major technological advances, globalization has delivered benefits to the world's societies but has been the target of criticism for allegedly harming certain groups and aggravating inflation, supply chain disruptions, trade disputes, and national security concerns.¹⁴⁶ Every industry and society in the globe are experiencing a rise in global awareness. All facets of society have been impacted by this change in attitude and behavior. The marketing of American consumer goods, industry, and even entertainment has significantly grown to a global level, rather than just concentrating on the United States. Multinational corporations have been established in order to participate in the wider economic arena as a result of the globalization of marketing, manufacturing, and competition. Even the economy has gone global. The global economy is impacted by the economic difficulties faced by Mexico, the United Kingdom, or any other nation.

Increasing Stress on the Environment: Concerns about the environment and its capacity to sustain the world's population in the future are getting harder to resolve. It may be feasible for one nation to manage its own pollution control; yet environmental issues transcend national borders. Around the world, conflicts between economic and environmental concerns persist. The utilization of old growth forests, the preservation of wetlands, fishing rights, and laws pertaining to chemicals that impact the atmosphere are also topics of discussion. As we face challenges from infractions like industrial runoff, our fresh water table will likely become more of a concern.¹⁴⁷ Because landfills are still overflowing with garbage, recycling is under more strain. Complex environmental phenomena, land development, and toxic waste all have a role in health education and the welfare of people and animals.

Increasing Speed and Dissemination of Information Technology: The globe is now connected in ways that were unimaginable fifty years ago because of mass media. Although this year's newest contribution to computers may be the Pentium chip, nanotechnology is rapidly approaching. From political science to microbiology, nanotechnology will enable the use of methods that will significantly reduce the size of equipment and boost information processing and dissemination capabilities. Bits of information are sent electronically fairly instantly these days. The Internet, social media, and major news networks all contribute to the rapid global dissemination of information. As a result, people can virtually instantly learn about events that have occurred halfway around the world. Information privacy is prac-

tically impossible.¹⁴⁸ The "bits" that make up information technology don't act like consumer items. At national borders, consumer products might be halted and their value declared. Bits are electronically transported across borders with little regulation. This could help to explain why there are permeable boundaries across communities, organizations, and people. For instance, the Chinese students were faxing and using other media to communicate with the rest of the world while they were protesting in Tiananmen Square. The Chinese authorities found it extremely challenging to regulate the instant information. Many cases are comparable.

Scientific and Social Change: The recent news that a sheep had been cloned portends what genetic engineering will bring. One of the scientific innovations that will transform our lives is genetic engineering. In addition to continuing to unlock the mysteries of the gene code, biomedical technology will fundamentally alter how we treat illnesses and cultivate and produce our food. New organizational, social, political, and educational institutions will be needed as society develops. Additionally, gender roles will be reframed and publicly disseminated. There will be minimal time lag between all of these adjustments. The ethical and spiritual aspects of human nature are influenced by each other in these four movements. The problem and issues facing leadership then become more about how humans can better comprehend, regulate, and improve nature and how we interact with it.¹⁴⁹ The world has always been filled with conflicts, violence, repression, and oppression, which lead to circumstances in which no one truly wins and to deadlocks that worsen both the human condition and economic order. Building a durable peace requires addressing the human cost, regardless of whether conflicts can be won. This responsibility now rests with our future leaders and followers. Expert authors explore how both leaders and followers can foster pacifism, peace-building, nonviolence, forgiveness, and social cooperation in Peace, Reconciliation, and Social Justice Leadership in the 21st Century. The complexities that leaders in the 21st century must navigate underscore the need for three essential pillars: systemic resilience, network leadership, and value-based leadership. Regardless of their location, industry, or organizational culture, leaders encounter a host of internal and external challenges that can affect their daily lives and professional responsibilities. Today's leaders must grapple with numerous fundamental issues that are pervasive across various contexts.

Honing Effectiveness. It is a continuous process of refining skills, fostering self-awareness, and adapting to changing environments, rather than a one-

¹⁴⁶ <https://www.piie.com/microsites/globalization/what-is-globalization>, accessed on 25 Jan 2026

¹⁴⁷ Orozco, F., Kilag, O. K., & Parinasan, M. A. (2023). Navigating Unpredictability: Exploring Fundamental Components of Crisis Management in Organizational Settings. *Excellencia: International Multi-disciplinary Journal of Education* (2994-9521), 1(6), 1-11, accessed on 25 Jan 2026

¹⁴⁸ Bonaconsa, C., Nampoothiri, V., Mbamalu, O., Dlamini, S., Surendran, S., Singh, S. K., & Charani, E. (2024). Mentorship as an overlooked dimension of research capacity strengthening: how to embed value-driven practices in global

health. *BMJ Global Health*, 9(1), e014394, accessed on 25 Jan 2026

¹⁴⁹ Kramskyi, S., Guo, X., Chmutova, I., Kryvobok, K., & Lozova, T. (2024). The race for global leadership and its risks for world instability: Technologies of controlling and mitigation. *Research Journal in Advanced Humanities*, 5(1), 178-191, accessed on 25 Jan 2026

time achievement. Effective leaders align their teams around a shared purpose, act as role models, and focus on both high-level strategy and the details of execution. Developing essential skills such as time management, prioritization, strategic thinking, decision-making, and completing tasks is the goal of this leadership challenge.¹⁵⁰ Contemporary leaders need to keep in mind that effective leadership is based on knowing what motivates people, how they respond to particular situations, and then having the faith in ourselves to change things.¹⁵¹ When anything goes wrong, good leadership entails taking full responsibility, not placing the blame on our team, and using it as a teaching moment.¹⁵²

Inspiring Others. This leadership challenge focuses on enhancing productivity by developing key skills like time management, prioritization, strategic thinking, and decision-making. It is important for contemporary leaders to keep in mind that effective leadership is based on knowing what motivates people, how they respond to particular situations, and having the faith to change things. When things go wrong, good leaders take full responsibility, don't point the finger at our team, and use the situation as a teaching moment. It moving beyond mere motivation to creating shared purpose and fostering engagement among diverse, often remote teams. In a rapid, technology-driven landscape, effective leaders must balance empathy, vision, and adaptability to foster genuine connection and, in turn, drive innovation and employee productivity.¹⁵³

Developing Employees. "Empowering others through effective coaching and mentoring is essential for fostering their growth and potential." Mentoring and coaching have a connection and can overlap. Coaches and mentors play different roles, even if the same leader may conduct both. The mentor and the coach, as well as the individuals they are assisting in the development of, should be aware of the distinction. The goal of coaching is usually to help someone overcome a present obstacle or problem in order to improve their performance on the job. Research has consistently indicated that companies with strong employee motivation and engagement, as well as high satisfaction and retention rates, exhibit distinct people management strategies from those with poor engagement. Processes for developing talent were important differentiators.¹⁵⁴

Leading a Team. Team-building, team development, and team management present another signifi-

cant obstacle. This involves particular leadership issues, such as fostering pride, offering assistance, collaborating effectively, managing a sizable team, creating team standards, and adjusting to a new team. A collection of guidelines or guiding precepts known as team norms influence how members of the team interact with one another. Clear, accepted behaviors are established by team norms, which specify how tasks will be completed and what members of the team can anticipate from one another. The success of a team depends on trust, which can be developed in this important way. Discussing and deciding on team norms is crucial when several individuals collaborate to solve issues and reach conclusions. A project manager or team leader must take into account the team norms that are important to him and the work.¹⁵⁵ Gaining insight into a leader's own viewpoint will enable him to consider his own conduct and efficient methods of team management.

Guiding Change. The 21st century is characterized by constant disruption and holds challenges for leaders in every sector. Dealing with economical and geopolitical situations today, business markets are volatile, customer behavior unpredictable, and geopolitical tensions are escalating. We've shifted from local to global, from isolated to interconnected. New technology such as ChatGPT can now generate entire workshop programs in seconds. This rapid digitalization has birthed new ways of learning, working, and connecting, turning us into citizens of a global society.¹⁵⁶ This change has reshaped organizational structures and demanded more from contemporary leaders as flexibility, empathy, and a people-centric approach have never been more important. However, as we move forward, leaders are met with novel challenges – fostering connectivity and performance in remote teams, coordinating fluid teams, bridging generational gaps, and leading change in a world where the only constant is change itself.¹⁵⁷ An effective change leader is more challenging due to the complexities of organizing and managing change. It requires understanding team members' reactions, overcoming resistance, and minimizing negative impacts. Successful change implementation is a key issue for modern organizations, as adapting is essential for survival and growth in today's fast-paced environment.¹⁵⁸ Contemporary successful leaders guide change by fostering a clear vision, acting as resilient role models, and engaging employees through transparent communication and empathy. They adopt a systems thinker

¹⁵⁰ <https://www.mckinsey.com/industries/public-sector/our-insights/honing-leadership-excellence-in-the-public-sector>, accessed on 25 Jan 2026

¹⁵¹ <https://www.linkedin.com/pulse/leading-excellence-power-continuous-honing-tumultuous-cortez-ggh6c>, accessed on 25 Jan 2026

¹⁵² Carvalho, A. M., Sampaio, P., Rebentisch, E., McManus, H., Carvalho, J. Á., & Saraiva, P. (2023). Operational excellence, organizational culture, and agility: bridging the gap between quality and adaptability. *Total Quality Management & Business Excellence*, 34(11-12), 1598-1628, accessed on 22 Mar 2026

¹⁵³ Vera, D., Samba, C., Kong, D. T., & Maldonado, T. (2020). Resilience as thriving: The role of positive leadership practices. *Organizational dynamics*, accessed on 25 Jan 2026

¹⁵⁴ Walters, D. W., & Helman, D. A. (2023). *The Value Chain Network: Unlocking Organizational Excellence Through Effective Operating Models*. Springer Nature, accessed on 25 Jan 2026

¹⁵⁵ Wallace, D. M., Torres, E. M., & Zaccaro, S. J. (2021). Just what do we think we are doing? Learning outcomes of leader and leadership development. *The Leadership Quarterly*, 32(5), 101494, accessed on 25 Jan 2026

¹⁵⁶ Tarba, S. Y., Frynas, J. G., Liu, Y., Wood, G., Sarala, R. M., & Fainshmidt, S. (2023). Strategic agility in international business. *Journal of World Business*, 58(2), 101411, accessed on 25 Jan 2026

¹⁵⁷ <https://www.effactory.com/knowledge/leadership-21st-century/>, accessed on 25 Jan 2026

¹⁵⁸ <https://www.ccl.org/articles/leading-effectively-articles/successful-change-leader/>, accessed on 25 Jan 2026

approach to understand impacts on people and processes, prioritizing adaptability, trust-building, and consistent, actionable feedback over rigid, top-down directives.¹⁵⁹

Managing Stakeholders. Managing relationships, navigating workplace politics, and shaping one's image are vital aspects of effective leadership. Securing buy-in from various departments, organizations, or individuals, along with managing up, influencing peers, and garnering support from management, are all critical components of this process. Influence encompasses the ability to implement key strategies that engage, connect with, and motivate others to change their behavior in a desired direction. While influencing others is essential, it goes beyond merely giving orders. Modern leaders not only provide direction but also inspire, motivate, and persuade.¹⁶⁰ They harness the expertise and skills of their teams, steering members toward a common goal and fostering a commitment to achieving successful outcomes. Research from the CoST Infrastructure Transparency Initiative, analyzing 480 major projects globally, found that 70% of infrastructure projects experience significant delays, with stakeholder and sustainability issues exceeding commercial delays (63%) and technical failures (21%) as the leading cause. In Australia alone, infrastructure opposition costs have reached an estimated \$20 billion.¹⁶¹ Research shows 67% of organizations report significant concern about knowledge loss, with an estimated \$72 million annual productivity cost across large enterprises.¹⁶²

V. Proposition of Effective Leadership Practice in 21st Century

Renowned professor Peter Drucker once stated, "Wherever you see a successful business, someone once made a courageous decision." In the 21st century, leadership will involve making multiple brave choices. Although it is more demanding, positive leadership will have a significant impact during these times. Currently, global business faces some of the strongest headwinds in history, second only to two world wars. Navigating an organization through such challenges requires leaders with courage, conviction, strong mental resolve, unwavering focus, and a clear sense of purpose. A leader cannot succeed alone, especially today. To meet organizational goals, leaders must be open-minded, willing to collaborate, capable of integrating diverse viewpoints, and charismatic enough to guide teams with varied motivations. The old view of corporate leaders as mere figureheads, chiefs, or commanders is quickly fading. While charisma and vision remain important traits, they are no longer sufficient. Success in today's fast-changing business environment depends on leadership versatility—being able to switch between roles, such as acting as a commander or a mentor, as needed. Effective leadership now requires the ability to operate

across generations, cultures, mindsets, and motivations below. Having a purpose is essential, but an inspirational one is even more vital. Leaders should possess a personal purpose—such as "what I want this organization to achieve"—that aligns with the organization's purpose, which is "what this organization stands for." Both companies and their leadership teams must have a purposeful vision that extends beyond just revenue and profit goals. Genuine commitment, a clear vision, and true belief in the purpose require leaders to embody those values—they must walk-the-walk, not just talk-the-talk. Leaders who fail to practice what they preach are quickly abandoned. The same applies to those who do not lead with clarity focus. Many leaders underestimate the power of networks both inside and outside their organizations. Some benefits of tapping into and leveraging networks include increased opportunities for collaboration and innovation includes:

- Gaining a deeper understanding of important stakeholders within the organization.
- Pinpointing obstacles that hinder teamwork and innovation
- Effective communication cascade to the key stakeholders.
- Identifying and attracting leading talent in the industry
- Finding new suppliers, innovative technologies, consultants, or industry leaders who can help boost your business performance is an exciting journey! Exploring these opportunities can open doors to new growth and success.
- Developing, designing, and executing impactful career pathways

Leaders in the 21st century must prioritize long-term strategy over short-term tactics and develop the ability to think and plan beyond immediate details. They should possess a forward-looking vision to guide strategic implementation. One effective approach is to identify internal stakeholders, investors, and shareholders who share similar long-term values and collaborate with them persistently. In 2016, S&P Dow Jones Indices introduced its Long-Term Value Creation Global Index, which assists investors in benchmarking companies with long-term growth potential. Additionally, leaders can emphasize long-term planning by clearly communicating objectives, a roadmap, and an implementation plan both internally and externally. It is stated that great leaders have an enhanced capacity for creative problem-solving.¹⁶³ They encourage others to do the same by learning how to accomplish novel and surprising things using the resources currently available, rather than constantly inventing the wheel. In the twenty-first century, leaders must be able to effectively handle challenges and innovate constantly. To do this,

¹⁵⁹ <https://www.ccl.org/articles/leading-effectively-articles/successful-change-leader/>, accessed on 04 Feb 2026

¹⁶⁰ <https://simplystakeholders.com/7-stakeholder-management-challenges/>, accessed on 04 Feb 2026

¹⁶¹ <https://infrastructuretransparency.org/2025/05/20/drivers-of-infrastructure-delays/>, accessed on 25 Jan 2026

¹⁶² <https://www.sinequa.com/company/press/sinequa-finds-over-two-thirds-of-it-leaders-are-concerned-by-organizational-knowledge-loss-from-employee-turnover>, accessed on 09 Feb 2026

¹⁶³ Deng, C., Gulseren, D., Isola, C., Grocutt, K., & Turner, N. (2023). Transformational leadership effectiveness: an evidence-based primer. *Human Resource Development International*, 26(5), 627-641, accessed on 09 Feb 2026

they must foster an environment where all staff members feel free to provide ideas and solutions and keep in mind that everyone has something valuable to contribute. This will significantly contribute to the development of an agile and adaptable organization that is prepared to handle upheaval. It is stated that great leaders have an enhanced capacity for creative problem-solving. They encourage others to do the same by learning how to accomplish novel and surprising things using the resources currently available, rather than constantly inventing the wheel. In the twenty-first century, leaders must be able to effectively handle challenges and innovate constantly.¹⁶⁴ To do this, they must foster an environment where all staff members feel free to provide ideas and solutions and keep in mind that everyone has something valuable to contribute. This will significantly contribute to the development of an agile and adaptable organization that is prepared to handle upheaval.

Contemporary leaders must never take their people for granted. Continuous investment in employees through skills training, coaching, and welfare is essential at all levels. Research indicates that millennials now make up about one-third of the global workforce, and they seek greater flexibility and control over their lives and careers while still aiming for career advancement. Leaders should recognize these widespread attitude shifts towards work and the workplace, yet stay grounded in core values to enhance brand equity and organizational culture. Neglecting people can lead to high turnover, hindered progress, and dilution of organizational strength vision.¹⁶⁵ Every day, people undergo changes in how they live, work, lead, manage, and communicate. In the 21st century, a leader must see subordinates as integral members of the organization, not just workers to direct. Leaders should cultivate a lasting environment of trust and community within the organization. Moreover, strategic communication is vital for leaders to guide their teams to do the right things, not merely correctly, by managing internal and external relationships to boost organizational growth.¹⁶⁶ Members expect leaders who can motivate them and have the skills to help achieve what they cannot on their own. A leader not only demonstrates good behavior but also communicates actions clearly. Actions must match words—"walk the talk." Today's leadership often involves team collaboration, highlighting that leadership is a shared relationship rather than a solo duty. Within organizations, effective communication among colleagues ensures timely, efficient sharing of information, task coordination, decision-making, and conflict resolution. Organizational communication supports essential human processes like conflict,

cooperation, authority, compliance, morale, cohesion, and relationship building. In the end, these efforts work together to better produce, sell, or serve clients, customers, or stakeholders, ultimately serving the public more effectively.¹⁶⁷ **Leaders of the 21st century motivate others to change their thoughts and actions in line with a compelling vision. Leadership effectiveness is influenced by factors like vision, communication skills, rational intelligence, emotional intelligence, and spiritual intelligence. Therefore, the core principles of 21st century leadership can be summarized as below.**

➤ Today, everyone can lead because everyone is serving. James M. Strock said that if leadership is essentially about serving others, then anyone should be able to switch between being a leader and a follower.

➤ Employees are an organization's most precious asset. As Mark Zuckerberg pointed out, I think this is one of the main advantages of greater openness and transparency: it highlights the importance of building better social bonds and being more reliable.

➤ Relationships are becoming more important in our environment than commerce.

➤ A connection between consenting, empowered adults is what leadership is all about. .

➤ The relationship of leadership is dynamic. Regardless of the issue, leadership is currently the answer. These days, managers are expected to exhibit visionary, charismatic, transformational and genuine leadership. It is stated that "followers" must do this in order to reach their full potential.²⁰⁹

➤ The important component of 21st-century leadership is well communication.¹⁶⁸

➤ There is no one-size-fits-all leadership style. Mahatma Gandhi stated that all actions reflect our priorities. The brain is a remarkable organ; it begins functioning as soon as we wake up in the morning and continues until we arrive at the office.¹⁶⁹

➤ Leadership roles are increasingly merging. Theodore Roosevelt once stated that words are powerful tools. I aim to convey to my audience that I am genuine, that I truly mean what I say, and that I stand firmly for the core principles that matter in civilization.

➤ A leader's distinctive role is to envision and promote a future vision. Some critics claim that Ronald Reagan's success across various careers, including his two terms as U.S. president, was due to fortunate accidents. However, this criticism lacks supporting evidence. Nonetheless, it is true that Reagan¹⁷⁰

➤ Love represents the highest form of leadership in relationships. As Martin Luther King, Jr. stated, everyone has the potential for greatness because everyone

¹⁶⁴ Ekemezie, I. O., & Digitemie, W. N. (2024). Best practices in strategic project management across multinational corporations: a global perspective on success factors and challenges. *International Journal of Management & Entrepreneurship Research*, 6(3), 795-805, accessed on 24 Feb 2026

¹⁶⁵ <https://martinroll.com/resources/articles/leadership/leadership-in-the-21st-century/>, accessed on 25 Jan 2026

¹⁶⁶ Gorman, L., & Ward, A. M. (2023). Accountability. In *Encyclopedia of Sustainable Management* (pp. 22-28). Cham: Springer International Publishing, accessed on 25 Jan 2026

¹⁶⁷ Fossum, L. B., (1989), Understanding organizational change: Converting theory to practice US: Thomson Crisp Learning, accessed on 04 Feb 2026

¹⁶⁸ <https://servetolead.com/tag/information-age/>, accessed on 04 Feb 2026

¹⁶⁹ <https://www.azquotes.com/quotes/topics/office.html>, accessed on 04 Feb 2026

¹⁷⁰ <https://www.azquotes.com/quotes/topics/president.html>, accessed on 13 Feb 2026

can serve. An employee doesn't require a college degree to serve; they only need a heart full of grace and a soul driven by that spirit love.¹⁷¹

➤ Character is a competitive advantage.¹⁷² **William Shakespeare said, 'Love all, trust a few, do wrong to none.' Winston Churchill stated, 'When you have to kill a man, it costs nothing to be...' polite.**

Beebe and Masterson defined communication as the process of acting on information. It involves sending and receiving messages simultaneously, enabling people to understand the world and share their understanding with others. Typically, in-person communication provides the best opportunity to clarify meaning and resolve misunderstandings. Many researchers have emphasized that how group members communicate significantly influences collaboration outcomes. Communication roles in the workplace include regulating interactions between employers and employees, motivating staff, balancing organizational needs and goals, and supporting decision-making. Common roles also encompass gatekeeper, liaison, bridge, isolator, cosmopolite, and opinion leader. Today, mastering communication skills is essential for leaders—no longer optional but necessary for achieving success. Leaders must communicate effectively because organizational performance depends on clear guidance. Communication ensures that organizational and business transactions—ranging from resolving simple stakeholder issues to making costly enterprise decisions—are carried out properly. At all levels and across functions, communication remains a critical indicator of effective service, delivery, and development. Leaders employ various communication methods during information flow, and managing these effectively fosters strong, well-informed, and purposeful work relationships. The leadership goal in the 21st century is greatly defined by effective communication follows to foster a supportive environment where individuals can thrive, develop, and coexist peacefully with one another. It needs to foster harmony with nature and ensure sustainability for future generations.¹⁷³ It also needs to build communities rooted in mutual care and shared responsibility, where every individual count and their welfare and dignity are valued and respected and supported. Effective communication is a crucial function for ensuring strong leadership in 21st century organizations. Therefore, modern leaders must be adept at utilizing advanced technologies. Additionally, it is essential to establish the right direction and align team members towards shared goals. Importantly, future leaders must recognize that subordinates are vital members of the organization, and providing consistent, sound leadership will signifi-

cantly influence employee motivation and performance. In this context, leaders need to implement effective strategies for clearly communicating direction to their team members.¹⁷⁴

➤ Concentrate on one main goal whenever feasible, but ensure it aligns with the overall context.

➤ Keep the discussion focused on two or three key points.

➤ Focus on the most important aspects points.

➤ Translate strategy to operating terminology.

➤ Repeat again.

➤ Explain the reasoning behind any actions or decisions taken decisions.

➤ Invite questions and wait for responses.

➤ Summarize and clarify clearly.

In 21st century the concept of collaborative leadership has been labeled with many terms, including shared, participatory, collective, cooperative, democratic, fluid, inclusive, roving, distributed, relational, and post-heroic. Although there is no consensus on a single name for this "new leadership," it is increasingly recognized that traditional hierarchical models are less effective in addressing the global complexity, rapid changes, interdependency, and multifaceted challenges we face today above.¹⁷⁵ Motivating the new, more educated workforce to be dedicated, self-sufficient, and lifelong learners will be the main issue in the information age. Democratic traditions serve as the foundation for this "people-focused" leadership style. It is based on the idea that "solutions are to be discovered in community" in group-centered organizations where "everyone can learn continuously" in the complex future. Followers are being changed into collaborators, lifelong learners, partners, and co-leaders. The command-and-control leaders at the top of the pyramid are facing pressure to adapt as the need for this new leadership increases. It is anticipated that they would develop into leaders who are instructors, mentors, stewards, facilitators, and designers. They are being pushed to become leaders who "live their words," set an example, motivate others, assign tasks, and serve.¹⁷⁶ Effective leaders understand that everyone possesses leadership abilities that need to be acknowledged and put to use. Therefore, our conceptual framework of what leadership is and what effective leaders do is being restructured by the new leadership paradigm. It is changing the function of followers and redefining how organizations are built for the twenty-first century. "The traditional organizational pyramids of the nineteenth century are falling, being replaced with upside-down pyramids and circles and linkages," reads a new brochure from the Robert Greenleaf Center for Servant-Leadership, which encapsulates this sentiment. The process at the core of

¹⁷¹https://www.academia.edu/63077572/A_new_approach_to_assessing_leadership_dimensions_styles_context, accessed on 13 Feb 2026

¹⁷² <https://servetolead.com/pope-francis-life-is-measured-by-love/>, accessed on 13 Feb 2026

¹⁷³ Groves, K. S., Feyerherm, A. E., & Sumpter, D. (2023). Cultural intelligence as a global leadership competency in disruptive contexts. In *Handbook of Cultural Intelligence Research* (pp. 214-231). Edward Elgar Publishing, accessed on 13 Feb 2026

¹⁷⁴ Mai, R., et al, (2003), *The leader as communicator – Strategies and tactics to build loyalty, focus effort, and spark Creativity*, New York: AMACOM, accessed on 04 Feb 2026

¹⁷⁵ Block, P., (1993), *Stewardship: Choosing Service Over Self-Interest*. San Francisco: Berrett-Koehler, accessed on 11 Apr 2026

¹⁷⁶ Holbeche, L. (2023). *The agile organization: how to build an engaged, innovative and resilient business*. Kogan Page Publishers, accessed on 13 Feb 2026

this transformation is referred to here as collaborative and reciprocal leadership.¹⁷⁷ Our goal is not to become fixated on a description or a single concept that characterizes the new leadership because collaborative leadership is more flexible and fluid, emphasizing relationships and people's needs. It is more crucial to help people learn the new leadership's goals and talents, as well as to explain to them how collaborative leadership concepts can benefit them in the situation, they choose to lead in. Integration of the past, present, and future is necessary for evolution or advancement.

This realization gives individuals a firm foundation from which to enter the unknown future with the knowledge that cooperative structures have worked successfully for people in the past and can provide guidance for how to jointly design the future in the face of constant change in an interconnected world.¹⁷⁸ The understanding that no one person has the answers to the complex issues that a group or organization must deal with is a fundamental tenet of collaborative leadership. In this situation, leadership calls for a set of values that enable everyone to take action and a method that lets the group's wisdom come to the fore. Understanding that people possess the knowledge and creativity to address the issues they encounter must be the foundation of these ideas. They promote the growth of groups that facilitate group efforts founded on a common goal, sense of ownership, and set of values.¹⁷⁹ The development of collaborative leadership has been greatly shaped by insights from the natural sciences and history. The traditional Newtonian view of a mechanical universe, where people simply follow instructions and rely on repeated, learned responses, has shifted toward a more organic, systems-focused, and dynamic understanding of how individuals, groups, and organizations function. This systems approach demands nonlinear, holistic, and multifaceted strategies that emphasize interactive participation, open communication, ongoing learning, and relationship-building.¹⁸⁰ Consequently, leadership becomes about creating systems, structures, and environments that foster interaction and learning. Leaders must ensure the right patterns are in place, with everyone sharing responsibility for learning.¹⁸¹ While adaptability and change are vital in this approach, certain core principles support the interaction and learning crucial to collaborative leadership. These principles guide leaders as described below.

➤ **Promoting.** It requires transitioning from individual contributor to strategic thinker, focusing on visibility, relationship building, and demonstrating next-level capabilities before receiving the title. It is a

Group Leadership Method By adopting a shared, diffused, and flexible definition of leadership, "post heroic" leadership departs from the idea that the "great man" holds the solutions. This is predicated on the idea that everyone has the capacity to be a leader and that different people handle leadership roles according to needs, circumstances, and requirements. Collaborative leaders foster settings that are open, encouraging, and allow information exchange while valuing the contributions of all individuals. At the same time, people are urged to grow as leaders and learn new things. Therefore, leadership means helping others develop and learn. The "leader" is a facilitator whose job it is to establish and maintain the "safe space" where individuals may find themselves and learn to relate to each other in a genuine way. This is an example of how leaders are fostering communities. The group, community, or organization now receives more attention than the individual leader did. The nominal leader may not even be visible at times. To achieve this major strategies include driving organizational change, cultivating executive presence, documenting achievements, and developing high-level emotional intelligence.¹⁸²

➤ **Structuring.** A Setting for Learning A learner-focused organization or group encourages ongoing introspection and self-improvement. The culture is ingrained with behaviors like listening, encouraging open-mindedness, asking for constructive criticism, exchanging ideas, and seeing conflict as a chance for personal development. Interaction among those closest to the issue or opportunity is encouraged in order to generate creative solutions. The group must operate "in a mode of inquiry, recognizing that nobody knows and everybody can learn continuously" in order to do this. Open communication, mutual trust, shared meaning, and a sense of collective responsibility develop when the group or organization practices learning together. "Communities of commitment where individuals are always learning how to learn together" is how it describes this. As a result, individuals can step outside of their comfort zones and take the risks that come with change management. It involves designing clear roles, responsibilities, and reporting lines to ensure accountability, efficiency, and strategic alignment. It transforms a group into a high-performing team by defining "who does what," reducing conflict, and providing the stability necessary for growth. Effective structures balance hierarchy for control with agility for innovation.¹⁸³

➤ **Supporting.** Relationships and Interconnectedness: In collaborative leadership, interpersonal connections and relationships emerge as a key dynamic.

¹⁷⁷Chaleff I., (1995), *The courageous follower: Standing up to and for our leaders*. San Francisco: BerrettKoehler, accessed on 11 Apr 2026

¹⁷⁸Goldstein, J. (1993), *Revisioning the Organization: Chaos, Quantum Physics and OD - An Interview with Margaret Wheatley*. Organizational Development Journal, 2(2), accessed on 13 Feb 2026

¹⁷⁹Greenleaf R. K., (1991), *The Servant as Leader*, Indianapolis: The Robert K. Greenleaf Center, accessed on 13 Feb 2026

¹⁸⁰Huda, M., Borham, A. H., Hashim, A., Ritonga, M., Almunawar, M. N., Anshari, M., ... & Hanafi, H. F. (2023, October). Strategic role of trust in digital communication: critical

cal insights into building organizational sustainability. In *Proceedings of the future technologies conference* (pp. 387-403). Cham: Springer Nature Switzerland, accessed on 13 Feb 2026

¹⁸¹Jerab, D. (2023). *How to Be an Effective Leader in Decision Making in an Unstable Environment*. Available at SSRN 4525803, accessed on 27 Apr 2026

¹⁸²<https://www.forbes.com/councils/forbescoachescouncil/2026/05/01/why-staying-busy-wont-get-you-promoted-into-senior-leadership-and-playing-golf-might/>, accessed on 27 Apr 2026

¹⁸³<https://indianleadershipacademy.com/how-to-build-high-performance-teams-in-hybrid-workplaces/>, accessed on 27 Apr 2026

Covenant relationships arise because of values like respect, honesty, expecting the best of others, and having the freedom to make one's own decisions. Mutual responsibility and trust are the cornerstones of these partnerships. Building people's and groups' ability to live these principles, to take advantage of their interdependence, and to understand that disagreement and differences may promote development and creativity are the main goals of collaborative leadership. The growth of a shared vision that enables individuals to establish shared goals, set common directions, and rise above self-interest is another way that relationships are enhanced. When people have a common vision and set of values, they may organize and manage themselves to complete tasks without the need for strict rules and regulations. It involves adopting a supportive, coaching-oriented approach to empower team members, building trust, and fostering a collaborative environment, which increases employee engagement and reduces stress. Effective supporters provide necessary resources, clear, consistent communication, and emotional support while encouraging autonomy.¹⁸⁴

➤ **Encouraging Power Sharing.** In order for leadership to be shared or collaborative, ownership and power must be shared across the business. It is implied by shared power that everyone is accountable for learning, leadership, and decision-making. Teams and groups are frequently utilized to reach choices, sometimes using a consensus format. Individual integrity and peer agreements serve as the foundation for accountability and responsibility. As individuals work together toward shared objectives, alliances and partnerships develop, leading to lateral networks of reciprocal influence. Several connections functioning in a fluid, flattened structure founded on partnerships, self-regulation, and interdependence might be characterized as this process. involves moving away from top-down, authoritarian control toward a collaborative approach that distributes authority, decision-making, and responsibility among team members. This approach fosters a culture of ownership, trust, and continuous learning, ultimately driving better organizational performance.¹⁸⁵ It may be explained as a lattice or grid in Re-inventing the Corporation, where power is located in the middle rather than at the top. As a result, networks that cross across and have fluid, shifting borders take the role of hierarchical systems. This network-like structure facilitates the best possible engagement, communication, and empowerment.

➤ **Putting Service and Stewardship into Practice.** Since stewardship flips hierarchical leadership on its head, it is the foundation of reciprocal or shared leadership. Stewardship is not about using privilege, power, and control, but about making sure that other people's needs are met. Stewardship now favors collaboration over hierarchy or patriarchy, empowerment over reliance, and self-interest over service. As a result,

the leader is "in service in lieu of control." This dedication can also be characterized as "wanting to serve first" in his seminal work, *The Servant as Leader*. One then aspires to lead as a result of purposeful choice. Whether or if people's needs are being met serves as the yardstick for collaborative leadership. People can establish a community of shared responsibility as long as they feel appreciated and valued as partners. It requires a fundamental shift from an ownership mindset or focusing on control, power, and personal gain to a caretaker mindset or focusing on serving people, resources, and the long-term mission. Servant leadership prioritizes the growth and well-being of others, while stewardship ensures these resources are managed responsibly for the future.¹⁸⁶

➤ **Appreciating Inclusivity and Diversity.** Leaders must learn to accept and value individual diversity in order for people to respect one another, develop trust, and communicate honestly. Respecting variety is the fertile ground that grows alliances, partnerships, and cooperative networks. However, understanding differences is the most important factor in achieving community. Respecting each person's viewpoint and unique style allows them to freely share their skills and ideas, allowing others to benefit from their collective knowledge. Additionally, fostering communal ownership and turning followers into stakeholders depend heavily on this inclusivity. It is the knowledge that diversity fosters creativity and greatness. Respecting many viewpoints, encouraging open-mindedness, engaging in conversation, and listening intently and sympathetically are all ways to promote genuine diversity. It is no longer just a corporate social responsibility initiative; it is a strategic business necessity that drives innovation, enhances employee engagement, and boosts financial performance. Inclusive leadership goes beyond having a diverse team and it ensures that varied perspectives are valued, respected, and leveraged in decision-making.¹⁸⁷

➤ **Making a Commitment to Personal Growth.** As effective leaders, it's easy to lose track of their own development in the fast-paced world of business in 21st century. But the success of their team, the leadership effectiveness, and their ability to achieve goals are all closely tied to their personal growth. Leadership and personal growth are two sides of the same coin. By focusing on leaders own development, they will not only become a more effective leader, but they will also enhance their personal well-being.¹⁸⁸ At its core, the shift to shared or collaborative leadership is a human metamorphosis driven by "A resolve to work on them first." The desire for one's "own healing" has been the driving force behind service. Being aware of how one's inner life influences their leadership, whether in a favorable or bad way, can help to instill humility and honesty in the leadership process. Leaders provide an

¹⁸⁴ <https://corporatefinanceinstitute.com/resources/management/supportive-leadership/>, accessed on 01 May 2026

¹⁸⁵ <https://www.linkedin.com/pulse/shared-leadership-power-sohini-bhattacharya-bvbd/>, accessed on 01 May 2026

¹⁸⁶ <https://www.transcendentsearchers.com/servant-leadership-stewardship-guide/>, accessed on 27 Apr 2026

¹⁸⁷ <https://www.speexx.com/speexx-blog/diversity-and-inclusion-in-leadership/>, accessed on 27 Apr 2026

¹⁸⁸ <https://www.linkedin.com/pulse/leadership-personal-growth-how-self-development-fuels-oliver-n-mark-xnw8e/>, accessed on 27 Apr 2026

example for others to follow by concentrating on their own personal development and mastery.

Great leader Mahatma Ghandi's said "We must be the change we wish to see in the world," and that reflects his recognition that leadership was centered on personal transformation. The right knowledge, instruction, and training can enable anyone to start using their leadership abilities. What behaviors or roles must collaborative leaders perform if these are the guiding principles of collaborative leadership? Actually, collaborative leadership serves the following purposes: it focuses on the goal rather than the definition of leadership; it is a new paradigm of leadership that is mutually beneficial and collaborative; and there are strong trends that are guiding us in this way. Establishing an atmosphere that encourages the practice of collective leadership begins with a common goal backed by a set of particular values or beliefs that are ingrained in each individual's actions. It takes some "inner labor" for someone who wants to exercise this type of leadership. The practice of genuine collective or shared leadership cannot take place without this internal effort. Values and beliefs are where this inner labor begins. All people are capable of leading themselves, according to those who practice shared leadership. They also think that the group's members, not just one leader, have the skills and assets required to complete a task.¹⁸⁹ Establishing a framework that enables individuals to lead themselves is the aim of positional leaders, rather than giving instructions or giving orders. In other words, positional leaders share or disperse the "power" that comes with their role. As a result, they let the group to take charge and learn how to collaborate, make decisions, plan, and take action. To the greatest extent feasible given the circumstances, they are able and willing to share the authority of their position. Their positional power is shared, yet their personal power is still apparent. The demand for positional power may be replaced or transformed into the satisfaction of witnessing the group develop into a community or learning organization. Modeling is a crucial component that comes after weaving the agreed vision. They have an honest vision of shared leadership, which is evident in how they organize and react to the group's growth. Because practice, vision, and modeling are all integrated, group members feel more confident that leaders "live their talk" by believing in each member and their collective action. It takes time for collective/reciprocal leaders to set up the space as a learning environment.¹⁹⁰ These could consist of: Initially, they establish the expectation of achievement. Secondly, the group is urged to challenge the status quo and embark on challenges. Even their own opinions about what they can and cannot do without explicit guidance from a positional authority are questioned.

A common goal backed by a set of particular values or beliefs that are ingrained in each person's conduct is the first step in establishing an atmosphere where collective leadership is performed. Anyone who want to exercise this type of leadership must put in some "inner labor." Authentic collective or shared leadership is not practiced without this inward effort. Values and beliefs are the foundation of this inner work. Shared leadership advocates hold that everyone is capable of self-leading. Moreover, they think that the group's members, not a single leader, possess the skills and assets required to complete a task. As a result, positional leaders aim to create a framework that enables individuals to lead them rather than to instruct or dictate. This indicates that the "power" of their positions is shared or distributed by positional leaders. They let the group to take charge and learn how to collaborate, make decisions, plan, and take action. They are competent and willing to delegate as much of the authority of their position as is practical given the circumstances. Although they share their positional authority, their personal power is still very much present. They could replace or transform the need for positional authority into the satisfaction of watching the group develop into a community or learning organization. After weaving the agreed vision, modeling is another crucial component. The way they organize and react to the group's growth demonstrates the integrity of their shared leadership vision. Group members are reassured that leaders "live their talk" by believing in each member and their combined action as a result of this integration of practice, vision, and modeling.¹⁹¹ Leaders that practice collective/reciprocal leadership invest time in creating an environment that is conducive to learning. This could contain: They first establish the expectation of success. Second, the group is urged to question the status quo and take chances. Without explicit guidance from a positional authority, individuals are even urged to question their own assumptions about what they can and cannot do.

VI. Proposition of Traits of Contemporary Successful Leaders in 21st Century

The role of leaders has also witnessed significant change in recent years, and the demands placed on leaders today involve complex transformation of societal value systems in the context of global political, social, and economic forces. These forces have generated new issues and heightened organizational uncertainty. In addressing these challenges, scholars and practitioners alike have begun to embrace an emergent realm that may be described as "spiritual" leadership. This concept is conceptualized through diverse genres, including the evolution of information, communication and management science development, social-psychological needs, across nationalities and cultural differences,

¹⁸⁹ Iriani, N., Agustianti, A., Sucianti, R., Rahman, A., & Putera, W. (2024). Understanding Risk and Uncertainty Management: A Qualitative Inquiry into Developing Business Strategies Amidst Global Economic Shifts, Government Policies, and Market Volatility. *Golden Ratio of Finance Management*, 4(2), 62-77, accessed on 13 Feb 2026

¹⁹⁰ Joel, O. T., & Oguanobi, V. U. (2024). Entrepreneurial leadership in startups and SMEs: Critical lessons from building and sustaining growth. *International Journal of Management & Entrepreneurship Research*, 6(5), 1441-1456, accessed on 27 Apr 2026

¹⁹¹ <https://www.harvardonline.harvard.edu/course/strategy-execution-public-leadership/> accessed on 13 Feb 2026

sociology of religion deviance and criminology, ecology, anthropological and cosmological theories of society and culture, mathematical semantics of social and anthropological relations, theories, and applications.¹⁹² The existence of the so-called naturally born leader is hardly supported by any data. Studies that are still being conducted are demonstrating the lack of value in the idea of a natural leader. The fact that charm is frequently confused with leadership could be one factor contributing to this misconception. It is true that certain leaders are very charismatic. But a lot of leaders don't. In actuality, a variety of forces shape leaders; they are not born. Honesty, knowledge, readiness, experience, opportunity, balance, and so forth are some of the elements that frequently create good leadership qualities. Astute leaders are starting to realize that it is their duty to cultivate followership by promoting followers' involvement in goal-setting and objectives.¹⁹³ Followers are now seen by modern leaders as collaborators in the company who should be empowered to carry out their duties and encouraged to seek innovation.

Contemporary successful leaders are believed to own the unique ability to inspire organizational members to seek an ideal and pursue that ideal by aligning with their personal values, goals, vision, mission, and sense of purpose. Individuals following a spirit-determined leader become members, instead of subordinates, feel at home in the organization, express emotions more freely, feel whole, and experience work engagement and personal fulfillment. These feelings of authenticity become the ultimate motivation for human action. Positive leadership abilities may have a positive and significant impact in almost every aspect of our lives, which is why leadership is vital. Gaining, comprehending, and demonstrating leadership abilities can positively impact our work environment, our community, and our interpersonal connections.¹⁹⁴ The ability to lead effectively in the present era requires a wide range of characteristics. Vision, mission, values, dedication, drive, and consensus-building are a few of these attributes. A leader's efficacy may be significantly diminished if they lack any of these crucial characteristics or traits. Contemporary successful leaders view the benevolence of people as final. They respect their words, feelings, emotions, and values and remain open and appreciative, totally committed and loyal to the growth and development of individual human potential. The value productive and effective leaders delegate responsibility. Such leaders demonstrate confidence in the abilities of people and rely on the resources of the organization to meet objectives. They support the right of people to make their own decisions and establish their own guidelines. Effective leaders promote self-satisfaction and integrity in order to foster an environment in

which people do the right thing not only because they think their boss is looking, but because they believe it is the right thing to do, and they feel fulfilled when taking the right path to their destination. The mission plays an even bigger role than the organization itself. It is a statement of the exclusive purpose that sets one apart from other organizations and as a driving force that propels growth and desired results.¹⁹⁵ The following are the essential characteristics of a contemporary leader.

Vision: This is a significant way to express the organization's mission in a way that is so visually appealing and intuitive that it effectively illustrates what the organization can become in the future. A shared goal, self-worth, and a feeling of belonging are all infused by vision. Historically, the organization's top management has provided the vision. Contemporary leaders are also starting to see the need of developing the vision in collaboration with individuals who are more familiar with the workplace and the client. Contemporary successful leader's vision is a clear, compelling, and actionable picture of a desired future, grounding, inspiring, and aligning team members toward common goals. Such leaders develop this vision by tapping into their core purpose, brainstorming future possibilities, and creating a narrative that aligns with organizational values.¹⁹⁶

Mission or Mission Statement: This usually explains the organization's mission and the kinds of tasks that must be completed for clients and stakeholders. The special value or services the organization provides as a result of its efforts should also be mentioned. Usually, mission statements have three or more parts. First, a declaration of the company's overarching goal or objective is made. Second, a declaration outlining the principles as staff members are supposed to uphold and adhere to during the decision-making process. Third, a statement outlining the main objectives that management feels are necessary to fulfill the purpose. These objectives ought to align with the moral principles that staff members are supposed to uphold. Contemporary leaders make sure that, these are the tenets that outline how staff members, starting with management, plan to carry out their duties and behave. These principles serve as the cornerstone of the organization's culture and will dictate the type of organization that emerges. Contemporary leaders never sacrifice moral courage or values.

Values: Values are the underlying beliefs that guide our decisions and actions and ultimately shape our days and careers. Our values determine how we execute leadership, the team environment we create, and the success of our company or venture. The values you display as a leader will permeate your entire organization and affect its performance. Leadership values are a

¹⁹² Khokhar, M. S., Agashe, A., Deogaonkar, A., & Paralkar, T. A. (2023). Ethical Leadership and Corporate Social Responsibility in Diversified Business Groups: A Conceptual Model of Asian and Latin America. *International Journal of Professional Business Review: Int. J. Prof. Bus. Rev.*8(6), 19, accessed on 13 Feb 2026

¹⁹³ Kramskyi, S., Guo, X., Chmutova, I., Kryvobok, K., & Lozova, T. (2024). The race for global leadership and its risks

for world instability: Technologies of controlling and mitigation. *Research Journal in Advanced Humanities*, 5(1), 178-191, accessed on 27 Apr 2026

¹⁹⁴ <https://aithor.com/essay-examples/qualities-and-characteristics-of-effective-leaders-in-the-21st-century>, accessed on 29 Apr 2026

¹⁹⁵ Ibid

¹⁹⁶ <https://www.indeed.com/career-advice/career-development/leadership-vision-statements>, accessed on 29 Apr 2026

subset of those values that positively influence one's ability to lead effectively or be a good leader. Leader should consider this question: What are the goals, mission, and culture of my company?¹⁹⁷ The guiding principles outline how the staff, starting with management, plans to carry out their duties and behave. As the cornerstone of the organization's culture, these principles will dictate the type of organization that emerges. Moral courage and values are never compromised by modern leaders.

Commitment: Commitment is the unwavering dedication to goals, people, and values, fostering trust through consistent actions, integrity, and follow-through. Contemporary and effective leaders demonstrate commitment by serving their team, modeling, and maintaining high standards. It drives organizational success and fosters a resilient team culture.¹⁹⁸ This is the emotional commitment made by an employee to put up significant effort in order to carry out a choice, result, or objective. To accomplish the mission and set goals, effective leaders must be dedicated individuals who can enlist the dedication of others. Contemporary leaders never waver in their dedication and cultivate goodwill. Understanding commitment as a crucial leadership trait is essential for fostering a motivated and resilient team environment. Leaders who display strong commitment not only drive their teams towards success but also cultivate a culture of accountability, perseverance, and continuous improvement. This overview delves into the various dimensions of commitment in leadership, exploring its key points, benefits, challenges, future trends, best practices, real-world case studies, and concludes with its overall significance.

Motivation: This is the capacity to offer a motivator or justification to persuade people to take action or make a commitment. Successful leaders understand that various people respond to different motivators since every individual is unique. A prudent leader is also aware that creating a fear-based atmosphere is the least successful long-term motivator and that money is not the best one. Contemporary leaders are able to effectively inspire their people. Motivating leaders relies on cultivating purpose, autonomy, and growth, driven by internal passion rather than just external rewards. Effective leaders stay motivated by focusing on vision, embracing continuous learning, building strong relationships, and achieving mastery. Major drivers include personal fulfillment, making an impact, and developing others.¹⁹⁹

Consensus Building: This is the capacity of a leader to foster consensus among disparate members of a group. Although it may not be every member's first choice, a consensus usually arises when different group

members concur that a specific alternative is acceptable. Compared to a decision reached by a simple majority, reaching a consensus can foster a higher level of commitment among group members. Nevertheless, reaching a consensus takes more effort and isn't always achievable. In order to start implementation, modern leaders typically need to take the initiative and confirm that the group decision has been taken.

The existence of the so-called naturally born leader is hardly supported by any data. Studies that are still being conducted are demonstrating the lack of value in the idea of a natural leader. The fact that charm is frequently confused with leadership could be one factor contributing to this misconception. It is true that certain leaders are very charismatic. But a lot of leaders don't. In actuality, a variety of forces shape leaders; they are not born. Honesty, knowledge, readiness, experience, opportunity, balance, and so forth are some of the elements that frequently create good leadership qualities. Astute leaders are starting to realize that it is their duty to cultivate followership by promoting followers' involvement in goal-setting and objectives.²⁰⁰ Followers are now seen by modern leaders as collaborators in the company who should be empowered to carry out their duties and encouraged to seek innovation. Positive leadership abilities may have a positive and significant impact in almost every aspect of our lives, which is why leadership is vital. Gaining, comprehending, and demonstrating leadership abilities can positively impact our work environment, our community, and our interpersonal connections. The ability to lead effectively in the present era requires a wide range of characteristics. Vision, mission, values, dedication, drive, and consensus-building are a few of these attributes.²⁰¹ A leader's efficacy may be significantly diminished if they lack any of these crucial characteristics. The following are the essential qualities/traits of a contemporary successful leader.

Humility. Humility for leaders is the quiet confidence to recognize one's own limitations, prioritize team needs, and foster a culture of trust and continuous learning. It improves performance and job satisfaction by empowering employees, admitting mistakes, and seeking feedback. Humble leaders show vulnerability, leading to stronger, more resilient teams. Being humble makes a leader "more human" and involves sharing power and soliciting input as opposed to forcing change and exercising command. The significance of humility in leadership cannot be understated. In the corporate world, the qualities of a successful leader are always evolving. However, one quality that remains important is humility. Although it may seem counterintuitive, humility can actually be a powerful tool for leaders.²⁰²

¹⁹⁷ <https://www.betterup.com/blog/10-core-values-of-a-great-leader>, accessed on 27 Apr 2026

¹⁹⁸ <https://auroratrainingadvantage.com/leadership/commitment-leadership-quality/>, accessed on 21 Apr 2026

¹⁹⁹ <https://naviminds.com/motivational-leadership/>, accessed on 21 Apr 2026

²⁰⁰ Longenecker, C. O., & Wittmer, J. (2024). CEO reflections on leadership lessons from the global pandemic: back to

basics during crisis. *Leadership & Organization Development Journal*, accessed on 21 Apr 2026

²⁰¹ McKenzie, C., Brophy, K., Konstanta, G., & Webster, L. (2023). A vision for change leadership: Trust, transparency and accountability at University of Wollongong Library. *The Journal of Academic Librarianship*, 49(3), 102710, accessed on 21 Apr 2026

²⁰² <https://managementconsulted.com/humility-in-leadership/>, accessed on 21 Apr 2026

Trust. A leader who exhibits humility is "more human" and shares authority and solicits feedback instead of forcing change and exercising command.²⁰³ Successful leaders build trust through a foundation of competence, character, empathy, communication, well-behavior, connection, earning confidence rather than demanding it. Contemporary successful leaders foster a culture of trust by being authentic, transparent, consistent, and empathetic, which drives team performance.²⁰⁴

Transparency. Trust and transparency must go hand in one. It is impossible to build trust without being truthful and transparent. Leaders that are open and honest with their team about how they can all work together to accomplish the company's goal see a 103 percent boost in employee satisfaction and an 87 percent rise in the quantity of excellent work that is being done. It is the practice of willingly sharing information, decision-making processes, and rationales with employees, fostering trust, accountability, and engagement. It involves honest communication, admitting mistakes, and explaining the "why" behind decisions. This approach reduces uncertainty, enhances employee motivation, and builds a resilient, inclusive company culture.²⁰⁵

Empowerment. Empowering leadership is a leadership strategy that focuses less on direct management or micromanaging employees, and more on allowing employees to administer themselves through empowerment. It means allowing employees the space and permission to make important decisions about how they work and the projects they participate in each day. Developing leadership skills often requires training and experience, but some companies also inspire better leadership among employees by adopting certain leadership models, like leadership through empowerment.²⁰⁶ Leaders that give their staff the freedom to take charge, make choices, lead, and innovate see a 78 percent boost in engagement, a 255 percent rise in the occurrence of excellent work, and an 184% improvement in their employees' perceptions of them.²⁰⁷

Enablement. It is a strategic and inclusive approach that empowers leaders with the tools, skills, and support needed to thrive, moving beyond training to cultivate high-performing cultures. It focuses on removing obstacles, enabling agility, enhancing human traits like empathy, and driving employee performance. Major components include data-driven insights, clear expectations, and continuous feedback loops.²⁰⁸ So, workers/staffs must be given the opportunity to change things. It is the duty of leaders to help their staff members grow and develop so they have the knowledge and expertise needed to do excellent work.²⁰⁹

Prioritizing Wellbeing. There's a great quote of Dalai Lama as he said "if you can't take care of yourself, you're not qualified to take care of anyone else". People are always at the heart of any organization, so when anybody take time to take care of themselves, they are actively investing in their health and essentially their team. Workers must be empowered to make changes. Leaders have a duty to nurture and develop their staff, giving them the knowledge and skills necessary to perform their best.²¹⁰ Repeating this often emphasizes its importance, but the core message remains the same: empowerment and development are key. Leaders should focus on supporting their teams to foster growth and improvement work. Many of us invariably fail when something happens and our plans are overturned. We need to remember that this is a marathon, not a sprint, establishing healthy routines and backup plans for when things don't go our way, being flexible and remembering that we can always begin again.

Mentorship. Employees must be allowed to change the world. Leaders are responsible for helping their staff members grow and develop, so they have the knowledge and experience necessary to perform excellent work. Employees must be allowed to change the world. Leaders are responsible for helping their staff members grow and develop, so they have the knowledge and experience necessary to perform excellent work. Employees must be allowed to change the world. Leaders are responsible for helping their staff members grow and develop, so they have the knowledge and experience necessary to perform excellent work.

Empathy. In the land of leadership, traditional notions of asset and assertiveness often overshadow the importance of empathy. Leaders are often expected to be authoritative forces to be reckoned with, people who live by the notion that the ends justify the means. Showing compassion has traditionally been misconstrued as a weakness or a sign that a leader can be steamrolled by their charges. It was believed that an authoritarian presence was necessary to maintain a tight ship and keep the team working consistently toward their goals.²¹¹ It's critical to comprehend and acknowledge the needs, feelings, and difficulties of others. Leaders who demonstrate empathy become far more relatable and build closer bonds with their staff. The current state of affairs is unparalleled in that everyone on the planet is coping with the same issue in their own unique way. Although COVID-19 had a global impact, each of us experienced it differently on a personal level. We all carry rocks in our backpacks, and some days those

²⁰³<https://www.octanner.com/global-culture-report#2020>, accessed on 21 Apr 2026

²⁰⁴ <https://www.facebook.com/100094160513856/posts/11-ways-to-build-trust-as-a-leader-leadership-trust-leader-leadershipskillsstudy/834411919707484/>, accessed on 21 Apr 2026

²⁰⁵ <https://www.linkedin.com/top-content/leadership/leadership-s-impact-on-culture/importance-of-leadership-transparency-in-company-culture/>, accessed on 13 Feb 2026

²⁰⁶ <https://ca.indeed.com/career-advice/career-development/empowering-leadership>, accessed on 26 Feb 2026

²⁰⁷ <https://fleximize.com/articles/017780/modern-leadership-todays-workplace>, accessed on 26 Feb 2026

²⁰⁸ <https://thisisalchemist.com/creating-a-successful-leadership-enablement-plan/#>, accessed on 26 Feb 2026

²⁰⁹<https://www.thegrowthfaculty.com/blog/modernleader>, accessed on 13 Feb 2026

²¹⁰ <https://www.myrtologaki.com/thinking/prioritizing-well-being-at-work>, accessed on 13 Feb 2026

²¹¹ <https://www.forbes.com/councils/forbestechcouncil/2023/11/16/empathy-in-leadership-the-powerful-balance-of-strength-and-compassion/>, accessed on 13 Feb 2026

rocks are heavier than others, as a quote suggests. Recognizing this is a fantastic first step.²¹²

Recognition. Giving regular praise and showing gratitude to others are essential for creating a contented team that is more inclined to go above and beyond. Employee engagement increases by 83 percent when people are consistently recognized, not simply when they achieve a goal. It is a critical tool that boosts employee engagement, retention, and performance by making team members feel valued, visible, and motivated. Effective leaders provide timely, specific, and authentic recognition that aligns with organizational goals while fostering a culture of trust. It is a powerful driver of productivity, not just a soft skill.²¹³ So, recognizing employees for their effort and contribution is essential for strong, effective leadership and improved organizational culture. 82% of employees are more engaged when recognized. Employees stay longer when they feel appreciated.²¹⁴

Honesty. It is the foundational practice of being transparent, consistent, and truthful, which builds deep trust, boosts team morale, and fosters a culture of integrity. It involves owning mistakes, sharing uncomfortable truths, and aligning actions with words, ultimately driving long-term organizational success. Contemporary successful leadership is a complex combination of character traits or habits and competencies or skills and practices and Which build a relationship of trust and influence. Only when followers see a never-broken pattern of honesty in the leader, will they be able to fully trust the leader. With the establishment of complete trust, followers can then invest their energy, livelihood, and commitment into the leader and the vision and goals that they are mutually pursuing.²¹⁵ In actuality, responsibility is fostered by honesty. Leaders that are truthful make their team members answerable for their activities. This can contribute to the development of a responsible, self-assured, and believing culture where everyone takes responsibility for their job and works to accomplish their objectives. In actuality, integrity is essential to good leadership and will remain so in the future. It strengthens faith, creates a positive culture, sets an example, welcomes criticism, and promotes accountability.

The contemporary successful leader, one needs have both theoretical and practical expertise. Real-world experience is how practical learning is achieved. The two primary approaches to learning and training in schools, colleges, and advanced adult education continue to be theoretical and practical instruction. On-the-job training is actually more beneficial than reading, watching, or listening. Learning by doing is the ultimate goal of vocational or practice-based, practical

learning nowadays. We can typically retain material effectively and for extended periods of time when we learn it practically.²¹⁶ Depending on the individual, actions are easier to recall and apply than words. Gaining more practical experience can help you grasp a certain skill or subject more thoroughly. It is frequently believed that experience-based learning is a more effective method of retaining information and honing skills. In contrast to theoretical learning, practice-based learning integrates interpersonal communication and teamwork. People are more likely to be studying alongside others than merely internally. Consequently, hands-on learning might enhance their communication and social abilities. In order to increase our capacity to collaborate with others in understanding and communication, social input may be essential for hands-on teaching and learning. By putting pertinent abilities into practice, a person develops the experience and knowledge necessary to finish tasks and demonstrate his ability in his position. The well-known proverb "practice makes perfect" applies here. The key to comprehending and demonstrating our ability to perform the job at hand in the workplace is practical learning. On the other hand, neglecting the significance of theoretical education will ultimately impede advancement.²¹⁷ The following abilities are necessary for contemporary leaders to succeed in their workplace or theater and stay away from harmful leadership practices.

Emotional Intelligence. The concept of emotional intelligence holds that both our own and other people's emotions have an impact on how we behave. High emotional intelligence is a sign of being able to identify one's own feelings and comprehend how they influence conduct. It also shows that you have the capacity to judge other people's feelings. The employment environment of today presents a different picture than that of previous roles where a rigid, structured leadership approach may have been effective. In order to help handle chaotic or stressful situations, leaders with emotional intelligence are able to comprehend the complicated feelings of both themselves and others. Inspiring others and preventing animosity, an emotionally savvy leader will effectively manage important client and workplace connections. Leaders with empathy are more than 40% more effective at coaching, decision-making, and staff engagement.²¹⁸

Listening Skills. It is common knowledge that all successful leaders possess strong communication abilities. However, it's a typical mistake to solely evaluate a leader's speaking abilities while ignoring their listening skills. Future leaders will adopt a stance of "actively listening" rather than completing employees' sentences or even providing interpretation since, as leaders, we

²¹²<https://councils.forbes.com/profile/Steve-Shillingford-CEO-Deepsee-ai/d67627e4-422f-4cfe-910a-9d7a6ea8795f>, accessed on 13 Feb 2026

²¹³ <https://www.startupdaily.net/advice/leadership/recognition-is-underrated-heres-why-its-your-most-valuable-leadership-tool/>, accessed on 19 Apr 2026

²¹⁴ <https://mustedu.com/the-importance-of-professional-recognition-for-team-engagement/>, accessed on 19 Apr 2026

²¹⁵ https://learn.neumann.edu/neureflections/csscd_8_28_2018, accessed on 13 Feb 2026

²¹⁶ Murphy, M. C. (2024). *Cultures of Growth: How the New Science of Mindset Can Transform Individuals, Teams and Organisations*. Simon and Schuster, accessed on 13 Feb 2026

²¹⁷ Nejati, M., Salamzadeh, Y., & Loke, C. K. (2020). Can ethical leaders drive employees' CSR engagement?. *Social Responsibility Journal*, 16(5), 655-669, accessed on 13 Feb 2026

²¹⁸ <https://www.soocial.com/emotional-intelligence-statistics/>, accessed on 13 Feb 2026

think our opinions are more significant. The finest thinkers have debated what intelligence really is for millennia. According to Einstein, "The true indication of intelligence is not knowledge but imagination," but Sternberg's theory distinguishes three types of intelligence: practical, creative, and analytical. Intelligence is up for discussion, regardless of how we define it. "Common sense" may be lacking in even the most "book brilliant" persons. IQ tests have historically been used to evaluate intellect, but they ignore social and emotional intelligence, two components of intelligence that are crucial for coaching and leadership. Listening carefully to clients and staff can assist address some issues by removing barriers and providing them with the will to succeed. A leader needs to hone his capacity to react to market cues. Sometimes a sudden change of direction is necessary, but more often than not, the early warning signs have been present for some time. Stronger ties with customers will result from that sensitivity. Since the world is constantly changing, a leader should be the "constant" that his clients depend on and provide them with the information they require to be successful.

Establish Trust. A prevalent characteristic among the world's top-performing teams is trust. Future leaders will create "psychological safety" in the group dynamic, allowing everyone to think freely and trusting one another to voice concerns and communicate openly. Teams at work can achieve better results more quickly and at a lower cost when there is trust. Future leaders will demonstrate trust in their employees, which will be reciprocated by more open communication as well as increased productivity and efficiency. Tech leaders today must become adept at conveying stories with strong graphics and remote tools because a large portion of the tech industry operates in a hybrid remote setup. Instead of delivering dull presentations, a tech leader should learn how to use their team's persona to communicate their messages, engage the audience remotely utilizing contemporary tools, and use square box cameras to gain their team's trust.²¹⁹

Develop Others. In 21st century leaders are developing others requires anchoring their thoughts to the individual and looking outside of the self. That personalization is one reason leadership coaching is so effective as a development tool. Being a modern leader means creating a strong leadership culture in addition to carrying out strategy and motivating outcomes. Today, the best leaders know how to draw out their employees' strengths. They also put in the time and effort to help them develop within their teams because they understand the impact this has on their organizations.²²⁰ By identifying and nurturing any leadership potential that may be developing within the firm, contemporary leaders go above and above for the benefit of the company's expansion. Successful leaders of the future will possess the quality of enabling people to realize their potential and accomplish their goals. Because in order to be a

successful leader in the future, we must enjoy helping people reach their full potential. However, a good coach and leader will set an example for their team members by making sure they understand how their job fits into the larger company objective and motivating them to remain motivated and dedicated to the organization.

Servant Leadership. The term servant leadership was coined by Robert Greenleaf, a twentieth-century researcher who was skeptical about traditional leadership styles that promoted authoritarian relationships between employers and employees. According to Greenleaf's observations, the servant leader approaches situations and organizations from the perspective of a servant first, looking to lend their presence to answer the needs of the organization and others.²²¹ A contemporary leader will exemplify the principles of a servant leader, who guides people to meet their needs. The welfare of the workers and their communities is the main focus of servant leadership. The wellbeing of their people is still the core focus of servant leadership, as opposed to traditional leadership's emphasis on company or business goals. A leader must begin considering people as individuals rather than as resources or items in his toolbox. People are not the tools in modern businesses; they are the people who use the tools. The first step in being a people-first leader is this lesson.

Global Citizen. In 21st century, global leaders confront a multitude of challenges shaped by historical events and technological advancements. The world has grown increasingly linked and borderless as globalization continues to dominate commerce and communication in society. In the future, contemporary leaders will have to overcome the challenges of navigating international marketplaces, appreciating new cultures, and building diverse teams of high-performing individuals. Successful leaders recognize the interdependence between themselves and their followers, fostering inclusive collaboration. Beyond mere authority, leadership encompasses inspiring, engaging, and fostering creativity among followers towards collective goals. Exceptional leaders serve their followers, harness their creative energies, and provide honest and timely feedback.²²²

Leading Integrations. As we approach another year of record merger and acquisition activity, the ability to lead integrations has become an increasingly vital skill set for technology leaders. Disjointed IT systems pose significant challenges following a merger or acquisition, particularly in today's dynamic work environment. Tech leaders who can effectively streamline disparate technology stacks and establish cohesive tech ecosystems will be essential in delivering value swiftly after a deal. Additionally, with the rise of remote work, tech leaders can no longer engage and connect with their teams by simply walking around the office. Instead, regularly sharing brief videos is an excellent al-

²¹⁹<https://councils.forbes.com/profile/Buyan-Thyagarajan-Partner-Salesforce-CRM-Practice-Lead-Eigen-X/3c11a4bedb76-439f-a535-e4150c348b60>, accessed on 11 Apr 2026

²²⁰ <https://www.soundingboardinc.com/blog/leadership-capability-develop-others/>, accessed on 21 Feb 2026

²²¹ <https://greenleaf.org/what-is-servant-leadership/>, accessed on 21 Feb 2026

²²² <https://ileading360.com/post-number-2/>, accessed on 26 Feb 2026

ternative for celebrating achievements, conveying information, or recognizing the efforts of individuals and teams.²²³

Digital Leadership. To effectively harness digital transformation, an organization typically has one or more leaders responsible for managing the transformation of assets and outlining the pathway to achieve its strategic objectives. These leaders focus on navigating the ongoing challenges of digital transformation as organizations adapt to evolving technology, new methods of product delivery, and shifting customer expectations. There is no one-size-fits-all approach or leadership structure that guarantees success in digital initiatives. Relying on a single leader may lead to the emergence of a digital silo, while distributed leadership can often result in a lack of alignment. In such cases, pursuing digital initiatives can feel akin to an infectious challenge: once a leader becomes involved, they may find it difficult to disengage. To avoid having the “infection” consumes valuable time, others may opt not to engage at all, leaving certain areas of digital development inadequately managed.²²⁴

Advanced Technology and Technology Leadership. Being a technology leader today requires more than technical expertise. Effective leadership involves a balanced skill set that adapts to the evolving tech landscape. Leaders must focus on the strategic vision while also attending to technical details, ensuring they don't lose sight of overarching goals. Striking a balance between hands-on skills and a broad outlook is crucial. Additionally, fostering a culture of cybersecurity awareness across all levels of the organization is essential, engaging everyone from interns to executives.²²⁵ In today's dynamic environment, an all-hands-on-deck approach is crucial. Emotional intelligence is a fundamental component of effective technology leadership, particularly in nurturing strong teams. Recognizing and addressing the emotional and professional needs of team members is essential for a leader's success. Technology leaders must adapt their management styles to align with the unique attributes of each individual. Since team members vary in their strengths and qualities, leaders should employ flexible management techniques to maximize each person's potential.

Adaptability and Continuous Learning. Change is a constant in the technology landscape, making adaptability essential for effective leadership. Leaders must not only respond to change but also actively embrace it. Technology leaders should foster a culture of continuous learning to enhance their teams' adaptability and resilience. This can be facilitated by promoting courses, webinars, and workshops. A tech leader's role extends beyond merely understanding code or keeping up with the latest trends; it encompasses a blend of technological expertise, cybersecurity awareness, emotional intelligence, and more. To effectively guide their

teams through the ever-evolving tech environment, leaders need to integrate practical skills with a strategic vision, encourage a culture of ongoing education, and advocate for ethical responsibility.²²⁶

Data Driven Decision Making. In technology leadership, possessing a strong data acumen is essential. A leader who neglects to engage with data risks making decisions based on guesswork, which is unacceptable in today's high-stakes environment. Effective technology leaders leverage data to derive actionable insights, rendering instinct-based decision-making obsolete.²²⁷ Data-driven decision-making (DDDM) for leaders involves using empirical evidence, analytics, and metrics rather than intuition alone to guide strategic, operational, and HR decisions. Leaders can achieve better performance by establishing clear, KPI-linked strategies, utilizing AI-driven scenario planning to model outcomes, and fostering a data-driven culture. Key steps include identifying the right data, implementing data analysis tools, and balancing data with human judgment.²²⁸

Strategic Vision and Foresight. It enables leaders to move beyond reactive management, using structured analysis to anticipate trends, risks, and opportunities, ensuring long-term resilience. Strategic foresight means leaders look beyond short-term gains, scanning the horizon for emerging risks and trends, and using imagination, planning, and resource shifts to build lasting value.²²⁹ Monitoring emerging trends is essential for technology leaders. What trends are currently influencing the industry? How can a leader ensure that their technology strategy aligns with broader business objectives? Effective technology leadership involves not only addressing present challenges but also anticipating future developments. Possessing foresight can provide a leader with a significant first-mover advantage.

Stakeholder Communication. Tech jargon can often feel foreign to those not working in the technology sector. Influential technology leaders have the ability to translate this jargon into clear, simple language that stakeholders can understand. In technology leadership, it is essential to bridge the divide between IT and other departments. Technology should not operate in isolation within a business. Leaders must create connections between IT and various departments to establish a cohesive strategy. As more individuals transition into strategic board-reporting roles, it becomes imperative for a leader to communicate the complexities of their job in layperson's terms. Mastering a successful ten-minute board presentation is a valuable skill that “equalizes” tech executives, setting them up for long-

²²³ <https://league.com/>, accessed on 26 Feb 2026

²²⁴ <https://www.ardoq.com/blog/digital-leadership-skills>, accessed on 11 Apr 2026

²²⁵ <https://www.linkedin.com/feed/hashtag/?keywords=cybersecurity>, accessed on 26 Feb 2026

²²⁶ <https://www.linkedin.com/feed/hashtag/?keywords=tech-leadership>, accessed on 26 Feb 2026

²²⁷ <https://www.linkedin.com/feed/hashtag/?keywords=datadriven>, accessed on 11 Apr 2026

²²⁸ <https://www.oakwoodinternational.com/blog/data-driven-leadership>, accessed on 11 Apr 2026

²²⁹ <https://www.linkedin.com/top-content/leadership/strategic-vision-in-leadership/leadership-behaviors-that-demonstrate-strategic-foresight/>, accessed on 19 Apr 2026

term success that can be passed on to their successors.²³⁰

Ethical Responsibility and Sustainability. Ethical leadership is a form of leadership based on strong moral principles and universal values, like integrity, transparency, and respect for others. An ethical leader stands out for their ability to inspire, attract, and motivate their team, creating a work environment where trust and mutual respect triumph. Transparency is a critical pillar of ethical leadership, as leaders who practice this style are open and honest in their communications, fostering a culture of trust and collaboration. With great power comes a significant ethical responsibility.²³¹ Technology leaders encounter ethical dilemmas that demand thoughtful consideration. Whether addressing data privacy or the ethics of artificial intelligence, it is imperative for leaders to navigate these moral challenges with care. Green technology is not merely a trend; it is an essential requirement. In the realm of technology leadership, championing sustainability is not only an ethical obligation but also a sound business strategy.

Creativity. Leadership requires fostering an environment where creativity and innovation can thrive. However, encouraging creativity isn't just about coming up with new ideas ourselves and it's about creating space for others to contribute their perspectives and solutions. It's about being open to change and seeing challenges as opportunities to do things differently.²³² Technology leaders should cultivate an environment that promotes innovation. It is essential for leaders to create a space where team members feel secure in presenting their next groundbreaking ideas. Embracing innovation often involves taking risks and challenging the status quo. In the realm of technology leadership, a willingness to disrupt established norms can lead to significant long-term advantages. A creative mindset is an open, mindset that effectively creates meaningful and active ideas and solutions. When a leaders adopt this mindset, he/she encourages problem-solving for their teams, opening up opportunities for business growth and new unexplored areas. When leaders innovate, they break the status quo to create products and services that differentiate them from others with a competitive edge. They build a culture of innovation by inspiring teams to exhibit their creativity collectively. However, creative leadership is one of the core leadership skills and will differentiate a great leader from a good one.²³³

Project Planning, Management and Delegation.

In 21st century, in the dynamic world of project management, efficiency isn't just a goal; rather it's an obligation. Among the many strategies employed to

achieve this efficiency, one stands out for its supreme impact of effective delegation. So, understanding and implementing the role of effective delegation in project management efficiency can be the linchpin in transforming good project outcomes into great ones.²³⁴ Projects must be completed on time and within budget. A great idea is only an idea until it is executed, making effective project management crucial for technology leaders to transform visions into reality. Demonstrating strong delegation skills reflects mature leadership. Leaders should recognize when to delegate tasks and trust their team's expertise to deliver results. Mastering project planning and delegation is vital for leaders aiming to meet their goals. Planning breaks down complex tasks into smaller, manageable parts, while delegation assigns responsibilities to ensure timely completion. Both skills help leaders stay aligned with their objectives and lead their teams to successful project outcomes.

Context Switching. Context switching for leaders is the ability to fluidly transition between disparate topics, meetings, and decisions—such as shifting from strategic planning to talent management—while remaining present and effective. While it risks causing a ~40% drop in productivity and high mental fatigue, mastering it fosters adaptability and faster innovation.²³⁵ Technology executives must enhance their understanding of context switching. For instance, they should adeptly shift their focus from sales to product development in an instant. It is essential for them to add value while processing new information and challenges efficiently, all while maintaining a keen sense of prioritization before swiftly transitioning to the next area of focus.²³⁶

Collaborating across Organizations. Today, cross-functional collaboration is a powerful tool that can drive organizational success by effectively bridging gaps between departments while fostering innovation across teams. With a better understanding of how collaboration can enhance organizational effectiveness, improve communication, and boost stakeholder engagement, leaders can be better prepared to foster collaboration in their own work.²³⁷ A technology leader must possess the capability to collaborate across the organization and assemble the appropriate individuals to develop innovative, comprehensive solutions that meet customer needs. This involves uniting various teams, particularly those that engage directly with customers, to gain insights into the product, identify pain points, and explore opportunities. Taking a holistic approach

²³⁰ <https://www.forbes.com/sites/forbestechcouncil/2022/03/18/16-skills-every-tech-exec-needs-as-their-role-evolves-and-expands/?sh=31a3cff124e9>, accessed on 26 Feb 2026

²³¹ <https://www.esade.edu/beyond/en/what-is-circular-economy/>, accessed on 26 Apr 2026

²³² <https://www.linkedin.com/pulse/innovation-creativity-leadership-scott-boersma-u5w8c#>, accessed on 11 Apr 2026

²³³ <https://www.forbes.com/councils/forbescoachescouncil/2022/07/14/how-to-embody-creativity-in-leadership/>, accessed on 11 Apr 2026

²³⁴ <https://www.omnitas.com/the-role-of-effective-delegation-in-project-management-efficiency/>, accessed on 27 Feb 2026

²³⁵ <https://www.linkedin.com/pulse/context-switching-underestimated-superpower-great-leaders-aadarsh-rohira-9idfc>, accessed on 11 Apr 2026

²³⁶ <https://councils.forbes.com/profile/Vivian-Wang-Founder-CEO-Landed/56495df1-2af4-4472-9465-3dd4f11a259c>, accessed on 26 Feb 2026

²³⁷ <https://ccaps.umn.edu/story/how-cross-functional-collaboration-drives-success>, accessed on 26 Apr 2026

to challenges is essential for successfully creating a product or service.²³⁸

Creating Automated Solutions. As technology evolves, tech leaders need a clear understanding of automation processes and strong communication with R&D teams to ensure successful product releases for customers.²³⁹ Creating automated solutions for leaders involves shifting from manual oversight to strategic orchestration, where AI, ML, DL, or IoT and automation handle routine tasks, data synthesis, and workflows, allowing leaders to focus on high-impact decision-making. Effective automation for leadership involves a shift towards data-driven decision-making, enhanced efficiency, and collaboration with intelligent machines.²⁴⁰

Adaptability. Adaptability is the ability to quickly, effectively, and proactively adjust strategies, mindsets, and behaviors in response to changing, uncertain environments. It involves emotional resilience, continuous learning, and fostering an innovative culture to turn challenges into opportunities for a leader.²⁴¹ The tech industry and consumer behavior are evolving rapidly, leading to shifting demands for businesses. The pandemic highlighted significant gaps in business continuity and security. In this context, a tech executive can truly excel by understanding these emerging needs and developing innovative solutions to address those gaps, thereby making businesses resilient for the future. Modern leaders must clearly articulate the importance of their top priorities, detailing the outcomes they achieve for the organization, and substantiate their claims with high-quality, market-driven data for a meaningful impact.

Comprehensive Digital and Smart Transformation. In 21st century, digital transformation is the strategic integration of digital technologies into every area of a business, reshaping how organizations operate, deliver value to customers, and remain relevant in an increasingly technology-driven economy. Its purpose goes beyond simply adopting new tools. At its core, digital transformation aligns people, processes, and technology toward long-term business resilience.²⁴² Tech leaders need to integrate all aspects of digital transformation AI, ML, DL, blockchain, cloud, and data—and develop products that create synergy across digital strategies. In today's environment, it is essential to focus on data-centric and cloud-based products. Blockchain should be utilized to ensure data immutability, while AI engines can enhance the accuracy of analytics.²⁴³

Bridging the Tech Knowledge Gap. Every tech executive must be able to communicate technical concepts in a way that non-technical people can understand. Bridging the knowledge gap between technical and non-technical audiences offers significant opportunities. When the team, customers, and others can better grasp what truly happens behind the scenes, everyone benefits. With the advent of ChatGPT, AI now aims to serve everyday users instead of being limited to those with deep technical expertise. Notably, ChatGPT is the fastest-growing consumer application in history, reaching 100 million users within the first two months of launch. While democratizing AI has exciting potential, it also raises societal concerns. Elon Musk and over 1,000 other tech leaders have called for a pause on AI development, citing fears about its negative impact on humanity's progress. The strength of AI lies in automating tasks that would otherwise be extremely time-consuming. It can dramatically boost organizational efficiency, but it also raises concerns about whether AI will replace human jobs and roles jobs.

Understanding of Quantum Technology. Businesses will face potential disruptions from rapid advancements in quantum technology. It's crucial to stay informed about these developments' technological and business impacts now, as the full potential of quantum will emerge in the medium term. Cryptographic agility is not just a buzzword; it is essential for transitioning to post-quantum algorithms. In the upcoming era of powerful quantum computing, where legacy encryption will be compromised, crypto-agility becomes vital for resilience. Notably, China is leading in quantum investment, reportedly unveiling a quantum processor a million times faster than the best supercomputer in October 2021.²⁴⁴

Innovation. Leaders prioritizing innovation can keep their organizations competitive, adapt to market changes, and unlock new growth avenues. During these discussions, they can explore methods for fostering an innovative culture, promoting creativity and risk-taking, and establishing processes to support new ideas. By investing in these strategies, leaders can ensure their organizations stay ahead in the market and leverage future opportunities successes.²⁴⁵ Effective innovation leaders exhibit certain distinct traits, much like an artist's distinctive style or a composer's unique melody. These qualities, a blend of personal characteristics, mindset, and leadership approach, make them capable of driving and nurturing innovation within their

²³⁸<https://councils.forbes.com/profile/Sujatha-Sagiraju-SVP-Product-Appen/d3b1adf9-f3c8-45b4-87e0-02dff3dbf9e3>, accessed on 26 Feb 2026

²³⁹<https://councils.forbes.com/profile/Judit-Sharon-CEO-OnPage-Corporation/493d9004-1273-469b-97a4-ff4019e71472>, accessed on 27 Feb 2026

²⁴⁰ <https://www.mygreatlearning.com/blog/automating-routine-tasks-with-ai/>, accessed on 26 Feb 2026

²⁴¹ <https://study.com/academy/lesson/video/adaptive-leadership-definition-examples.html>, accessed on 26 Feb 2026

²⁴² <https://www.vegam.ai/digital-transformation>, accessed on 26 Feb 2026

²⁴³<https://councils.forbes.com/profile/Rohit-Sehgal-Founder-CEO-Vincilium/6e81215a-c9dd-4f26-954f-618364200b9a>, accessed on 13 Mar 2026

²⁴⁴<https://thenextweb.com/news/china-says-has-quantum-computer-1-million-times-more-powerful-googles>, accessed on 13 Mar 2026

²⁴⁵<https://www.togetherplatform.com/blog/10-must-have-leadership-discussion-topics-for-rising-talent>, accessed on 13 Mar 2026

organizations. Collaboration is key to driving innovation. Leaders can foster a collaborative culture for success in workplace.²⁴⁶

Diversity, Equity, and Inclusion. Leaders who advocate for diversity, equity, and inclusion can help cultivate a workplace that is more inclusive and fairer, where all employees feel recognized, respected, and supported. By embracing diversity, leaders promote understanding and value for different perspectives and backgrounds. This encourages a culture of inclusivity and respect, fostering collaboration and open communication among staff, which can boost productivity. Additionally, leaders can consider strategies to build a diverse and inclusive team, address unconscious biases, promote fairness and equity, and establish a sense of belonging. In 21st century, successful leadership must go beyond traditional notions of authority and control. It requires embracing Diversity, Equity, and Inclusion (DE&I) as foundational principles that drive organizational success. Today, effective leaders seek out education and training to improve their understanding of DE&I issues and stay updated on best practices. They hold themselves accountable for fostering DE&I within their teams and organizations, embracing feedback and making necessary adjustments to ensure progress and positive change.²⁴⁷

Effective Virtual Leadership. It involves leveraging clear, transparent communication, trust-building, and high emotional intelligence to guide remote teams. Key strategies include setting explicit, outcome-based expectations, using collaborative technology, and conducting regular, structured check-ins to maintain cohesion and accountability without micromanaging.²⁴⁸ In 'Remote Work Statistics and Trends in 2024', Forbes reports that as of 2023, 12.7% of full-time employees work from home and 28.2% work a hybrid model. Additionally, according to Upwork, an estimated 22% of the workforce (32.6 million Americans) will be working remotely by 2025. However, office work might not disappear completely, it's clear that more and more companies will start embracing the benefits of remote and hybrid workforces.²⁴⁹ It given that remote or hybrid workplaces present unique challenges compared to traditional office environments, leadership skills must be adapted to this specific setting. Leaders should address collaboration obstacles, reliance on digital tools, and reduced face-to-face supervision or interactions in their management approach. As remote work and virtual teams become more prevalent, effective virtual leadership is increasingly vital. Leaders capable of guiding and managing remote teams help ensure consistent per-

formance, engagement, and collaboration across different locations and time zones. They should explore best practices, including effective communication, trust-building, and team-building strategies. Additionally, leaders must consider how to mitigate feelings of isolation among remote employees and foster a strong sense of belonging within virtual teams.²⁵⁰ Emphasizing open communication and trust, along with strategies like regular check-ins and online team activities, can support a positive remote work culture activity.

Problem Solving. By default, great leaders are the great problem solvers. They have good problem-solving skills with the right tools and focus to guide their teams through problems to specific solutions. Effective problem-solving for leaders involves a structured approach—diagnosing root causes, analyzing data, brainstorming, and implementing solutions—rather than quick fixes.²⁵¹ This skill can guide their organizations through challenges, embrace change, and discover new growth opportunities. They understand various problem-solving frameworks, strategies for diagnosing issues, and methods for creating and assessing solutions. These qualities make such leaders essential to their teams and organizations, driving them toward success. Moving forward, our understanding of leadership, development, and leadership education should continue to evolve change.²⁵²

Conflict Resolution. While a large part of effective leadership entails making strategic decisions and driving business success, it also means navigating and resolving conflicts that inevitably arise within teams and workplaces. When mishandled, conflict can severely impact morale, productivity and overall organizational health. However, adeptly managed conflicts can strengthen teams, foster innovation and build resilient workplaces. Every successful leader, therefore, must master the art of conflict resolution.²⁵³ Successful leaders' adept at conflict resolution can facilitate discussions between conflicting parties, foster a safe environment for open communication, improve team dynamics, and guide collaborative efforts towards resolving issues. They also promote mutual understanding and empathy between parties, which are crucial for achieving a successful outcome.

Inspiring and Influencing Team. In today's fast-paced and ever-changing business environment, effective leadership is more crucial than ever. A positive leader not only drives results but also fosters a supportive and innovative workplace culture. Leaders who lead by example can motivate and inspire their teams, fostering a positive work culture and encouraging employ-

²⁴⁶ <https://executive.berkeley.edu/thought-leadership/blog/leadership-innovation#>, accessed on 13 Apr 2026

²⁴⁷ <https://www.dhrglobal.com/insights/the-role-of-diversity-equity-inclusion-in-effective-leadership/>, accessed on 13 Apr 2026

²⁴⁸ <https://redshoemovement.com/virtual-leadership-dos-and-donts/>, accessed on 01 May 2026

²⁴⁹ <https://www.forbes.com/advisor/business/remote-work-statistics/>, accessed on 13 Mar 2026

²⁵⁰ Orozco, F., Kilag, O. K., & Parinasan, M. A. (2023). Navigating Unpredictability: Exploring Fundamental Compo-

nents of Crisis Management in Organizational Settings. *Excellencia: International Multi-disciplinary Journal of Education* (2994-9521), 1(6), 1-11, accessed on 13 Mar 2026

²⁵¹ <https://acorn.works/blog/problem-solving#>, accessed on 13 Mar 2026

²⁵² https://ilaglobalnetwork.org/books_/leadership-2050-critical-challenges-key-contexts-and-emerging-trends/? accessed on 13 Mar 2026

²⁵³ <https://www.park.edu/blog/conflict-resolution-strategies-every-leader-should-master/>, accessed on 01 May 2026

ees to aim high. By sharing their own experiences, leaders demonstrate that significant achievements and meaningful change are possible. This approach fosters unity and collaboration within the workplace, creating an environment that motivates employees to work harder and pursue their goals excellence.²⁵⁴ A positive leader understands the importance of mental and emotional well-being. Encourage work-life balance, promote wellness initiatives, and provide resources for stress management. When employees feel supported and valued, they are more likely to be productive and engaged.²⁵⁵

Contemporary successful leaders should delegate more to others. Doing so will enhance their productivity in addressing leadership challenges and empower colleagues to take greater ownership. Leaders can also foster greater trust within their teams by delegating effectively delegate more.²⁵⁶ Leaders need to proactively set goals and define timelines, deadlines, and essential steps to maintain progress for themselves and their teams. Distractions can cause them to lose focus on both short-term and long-term objectives. They often become sidetracked by urgent, unexpected issues instead of concentrating on outcomes that genuinely matter to their organization. Effective delegation goes beyond simply assigning tasks; it involves a continuous cycle of critical steps to ensure success follows. Effective delegators prioritize their tasks, choosing which to handle themselves and which to delegate.²⁵⁷ Leaders also recognize the level of feedback they desire while the delegated person completes the task. To delegate effectively, leaders need to assign tasks to individuals who possess the appropriate knowledge and skills. This requires understanding their team members. Delegation should also serve to help direct reports grow and learn as they handle new responsibilities tasks. A task's purpose provides it with meaning. When this purpose aligns with the beliefs and goals of the team or individual, delegation transforms into an opportunity for personal growth. Leaders should collaborate with their direct reports to find ways to support them. They should also determine if a task has been completed correctly and reward employees accordingly. Again, employees are likely to rally behind a change if they trust the people leading it. Building trust starts with transparency and success. When employees have a voice, they feel valued and more in control, which reduces anxiety. Moreover, those on the front lines often have practical insights that can improve the change plan. So, leadership provides direction, stability, inspiration, and helping teams understand and those are the reasons for change and guiding them through uncertainty. Again,

Transparency, honesty about challenges, involving employees in planning, listening to feedback, and maintaining visibility and accountability.²⁵⁸

Contemporary successful leaders focus on their unique strengths because they face more demands on their time and energy than they can handle. They should identify the tasks only they can accomplish and delegate the rest to their team. By concentrating on their distinctive contributions, leaders can overcome challenges and add value to their organizations. Recognizing their own qualities, behaviors, and habits helps leaders identify what obstacles might be hindering their growth. This awareness enables them to develop specific skills and advance as leaders. Common internal challenges include confidence issues, fear of failure, maintaining authenticity during self-promotion, impatience, resistance to new ideas, and impostor syndrome—all of which can block leadership success. Knowing their strengths and weaknesses and focusing on their unique value enhances self-awareness and personal leadership development brand.²⁵⁹ Again contemporary successful leaders must prioritize strengthening team alignment and collaboration. What factors might be hindering their team's ability to work cohesively and effectively together? It could stem from a lack of openness and honesty among team members, or perhaps insufficient time dedicated to celebrating small victories. Regardless, enhancing team alignment is essential for organizational success, enabling leaders and their teams to make difficult decisions confidently and maintain a calm, positive demeanor during crises. In challenging times, building trust becomes paramount; in fact, it is one of the three essential keys to effective team-building and collaboration. Without trust, individuals tend to operate out of fear, which jeopardizes success. Furthermore, adhering to agreed-upon principles can significantly align a leader's team. Examples of such principles include a commitment to values like accountability, mutual respect, and integrity.²⁶⁰ For collaboration to be both effective and structured, teams should follow a framework consisting of three main components or levels. In **structural level, they need to** recognize the structures, roles, and responsibilities of every team member. In **systemic level, they need to** evaluate the existing systems, processes, and policies rigorously. **Finally, in interactional level, they need to** assess the effectiveness of communication within the team.

Contemporary successful leadership emphasizes improvement and empowering individuals. It provides a clear purpose and focuses on creating and achieving goals. Leaders aim to transition from a current state to

²⁵⁴<https://www.togetherplatform.com/blog/10-must-have-leadership-discussion-topics-for-rising-talent>, accessed on 01 May 2026

²⁵⁵ <https://prsgllc.com/leadership-7-ways-to-inspire-and-motivate-your-team/>, accessed on 01 May 2026

²⁵⁶<https://www.ccl.org/articles/leading-effectively-articles/build-trust-in-the-workplace/>, accessed on 23 Apr 2026

²⁵⁷ Pontes, D., Santos, V., Samões, O., Wang, S., & Figueiredo, R. (2024). Towards Internationalization: Exploring Economic Diplomacy in the Middle East (GCC). *Economies*, 12(4), 82, accessed on 23 Apr 2026

²⁵⁸ <https://www.techclass.com/resources/learning-and-development-articles/leading-through-change-practical-tips-for-managers-and-executives>, accessed on 23 Apr 2026

²⁵⁹ <https://www.ccl.org/articles/leading-effectively-articles/whats-your-leadership-brand/>, accessed on 23 Apr 2026

²⁶⁰ <https://www.ube.ac.uk/whats-happening/articles/essential-qualities-of-a-great-leader/>, accessed on 23 Apr 2026

a better future while sometimes maintaining an effective status quo. Responsible management of resources is vital, with a focus on a circular economy rather than endless growth, always considering the impact on people and ecosystems. Leadership today balances authority with collaboration, valuing mutual agreements and employee input. Employees are increasingly seen as partners rather than subordinates, with compensation based on results rather than hours worked. Contemporary leaders are committed to developing employee potential while prioritizing the collective good and promoting a learning culture. They navigate disruptions strategically and aim to improve the world, fostering an environment where everyone can contribute their strengths. By practicing restraint, modern leaders remain aware of the impact of their actions and ensure decisions consider both short-term and long-term effects. In 21st century, honesty, adaptability, and balance are key leadership traits for successful leaders. Mentoring and coaching are powerful tools that serve as guiding lights for aspiring modern leaders, helping them navigate the complexities of today's world.²⁶¹ Coaches assist future leaders in becoming more agile, flexible, and adaptable by providing them with the necessary tools to handle change, complexity, and uncertainty. During coaching, coaches identify critical areas where the coaches need improvement and offer tailored guidance to develop those skills. Whether it's communication, analytics, decision-making, or conflict resolution, coaching makes future leaders more effective and efficient in their roles. Coaches give honest feedback and hold the coaches accountable for their actions and decisions. This accountability encourages a culture of continuous improvement, self-development, and personal responsibility. Leaders often face complex challenges and critical situations.

Coaching prepares them with problem-solving techniques, decision-making strategies, and methods to address issues effectively and intentionally. It is a structured, goal-oriented process dedicated to leader development. Typically, coaching hones specific skills and promotes goal achievement. A coach, who is an expert in a particular area, helps the coaches set and reach clear objectives. Coaching can be short-term or project-based, focusing on skill building, problem-solving, decision-making, and performance improvement etc. Mentoring is a dynamic relationship between an experienced individual (mentor) and a less experienced newcomer (mentee). The mentor provides guidance, support, and wisdom gained from their own experiences, helping the mentee grow personally and professionally. This often involves a long-term commitment, fostering trust, close relationships, and connection.²⁶² Skilled mentors share their knowledge and wisdom, helping mentees avoid common pitfalls and navigate

challenges more effectively. Since leadership can be lonely and demanding, mentors also offer emotional support, acting as trusted confidants by listening, empathizing, and guiding during tough times. Beyond professional growth, mentoring encourages personal development. It's a vital tool for succession planning, ensuring a pipeline of ready leaders for key roles. Both mentoring and coaching are essential in nurturing future leaders, offering guidance, wisdom, and emotional support. Together, they empower aspiring leaders to develop confidently and tackle future challenges. However, finding the right mentor or coach at the right time can be difficult, and these relationships require effort and commitment from both sides.

Contemporary successful leaders often feel overwhelmed, but they should remember they're not alone. By adopting a few positive behavioral strategies, leaders can overcome these challenges, adding more value to their organizations. There will always be more demands than time and energy to address everything do.²⁶³ By understanding and applying the framework discussed above, leaders in any organization will achieve clearer role definitions and enhance their team's alignment, both of which are essential for effectively responding to top leadership challenges. A contemporary successful leader has the skills and traits needed to manage a team now and in the future. Today's leaders must define a vision and execute a plan, but inspiring, motivating, and communicating with employees is just as important for achieving business goals. Since the future is always unpredictable, modern leaders need to innovate, adapt, and thrive in today's business and social environments. They also need to stay ahead in strategy and operations because successful teams, professionals, and organizations of the near future will require leaders who can adjust to innovation and major societal changes.²⁶⁴ Now, millennials have made up around 75% of the workforce, so most executives will manage a different generation with unique values. Future Gen X and Gen A leaders should recognize this generational shift by understanding what it takes to lead their millennial workforce, as Gen X leaders hold the most senior leadership roles worldwide. As technology and work conditions continue to evolve, the corporate sector changes rapidly alongside generational shifts. Future leaders will need to navigate these changes while embracing new developments or tackling complex problems as they emerge period.²⁶⁵ In 21st century, the business climate requires intentionality and adaptability. By embracing open communication, leading by example, fostering collaboration, and prioritizing employee well-being, we can create a thriving workplace culture. Contemporary successful leadership

²⁶¹ Rayets, M., Tkachuk, V., Buryk, M., Kubitskyi, S., & Zhaldak, H. (2023). The role of leadership in stimulating innovation and the creative potential of the team, accessed on 29 Mar 2026

²⁶² Rozell, E. J., & Spangler, H. (2024). Societal Impact: Beyond Frameworks. *Electronic Journal of Business Ethics and Organization Studies*, 29(1), accessed on 29 Mar 2026

²⁶³ <https://www.linkedin.com/pulse/how-respond-leadership-challenges-around-world-robert-ford/>, accessed on 23 Apr 2026

²⁶⁴ <https://hidayatrizvi.com/contemporary-leadership-theories/>, accessed on 29 Mar 2026

²⁶⁵ <https://www.linkedin.com/pulse/future-leaders-6-key-skills-required-next-gen-tony-nutley/>, accessed on 23 Apr 2026

need to set the tone for their team, and a positive approach can lead to enhanced performance and overall success in any venture or business.

VII. Conclusion

Throughout history, new technologies have contributed to the exponential growth of human knowledge. These days, a growing number of software programs are creating settings where leaders can direct the growth of their own expertise and intelligence with little assistance from coaches or mentors. The possibility for cost savings is one advantage of digital and smart technologies. The importance of cutting-edge technologies is increased in the current situation as they work to aid overburdened leaders in deploying the next wave of assistive technology in the near future. The idea that technology is the only solution to organizational problems seems overly definite in this day and age, which is marked by the rapid development of digital or smart technologies and the growing need for stronger machinery and equipment to support software and application upgrades. In the modern era of scientific and technological breakthroughs, it is essential to produce human resources that are skilled, competent, and have a purpose. The technology in question holds great promise for the professional and personal development of contemporary leaders and is essential to the general development and maturation of organizations, societies, countries, and human resources. There are benefits and drawbacks to advanced technology, particularly digital and smart technologies, when it comes to developing leaders. But it's crucial to recognize that these boundaries are unavoidable and shouldn't be disregarded. Additionally, workplace toxicity is a prevalent concern that can impede the performance of employees and the overall profitability of an organization. So, contemporary leaders to be aware of the opinions, worries, and recommendations of their teams, employee listening technologies have become an essential tool. When it comes to making strategic, business-oriented decisions, leaders in government, non-profit, and educational institutions confront particular difficulties. If these choices are not carefully thought out and carried out, there could be serious repercussions. In present contest, contemporary leaders need to employ varied leadership styles, from autocratic in high-risk scenarios to democratic for fostering creativity and inclusivity. Moreover, transformational leadership, with its focus on inspiring and motivating teams, will be a significant driver in the realization of strategic organizational goals and success.

In 21st century, the business landscape has changed, and the same is therefore true of the traits and characteristics that individuals believe their leaders should possess. Today's business leader is perceived as being transformational, virtuous, authentic, ethical, balanced, innovative, flexible, and of course effective. Today, digitalization and smart technologies are set to transform how contemporary leaders engage with their teams and stakeholders. Leaders will need to adopt new communication and collaboration methods to stay ef-

fective and successful. Additionally, the growing emphasis on diversity, globalization, and inclusion in the workplace is significant. This shift will require leaders to develop new skills and strategies to manage and motivate diverse teams, becoming more aware and sensitive to the needs of team members from various cultural and regional backgrounds. Globalization will demand strong connections with friends, foes, colleagues, and stakeholders across diverse cultures, attitudes, and backgrounds, along with an understanding of international markets and regulations. Leaders who integrate sustainable practices into their tasks and operations will be better prepared to compete in this rapidly evolving world. Interestingly, the value of global trade reached a record US\$ 7.7 trillion in the first quarter of 2022, according to the United Nations Conference on Trade and Development. Today, global trade includes both the exchange of goods and services.²⁶⁶ Global leadership necessitates the cultivation of a global mindset. Next-generation leaders adeptly navigate the international landscape, forge cross-cultural connections, and promote growth for businesses and communities worldwide. To develop a global mindset and a versatile attitude, one must begin with the ability to communicate a clear vision. Contemporary successful leaders are required to think strategically, build relationships, and inspire collaboration. In order to succeed as a global leader, it is essential to effectively navigate the challenges and seize the opportunities presented within a dynamic and diverse international ecosystem. Contemporary leaders must embrace a more contemporary management approach in order to achieve success. Leadership has always been an indispensably imperative instrument to the leaders in steering the development of an organization, a country or the globe as a whole in a relative dealing with associated contemporary factors in every era everywhere in every civilization.

Contemporary leadership has several drawbacks compared to traditional leadership. Leaders and followers might not be on the same page. It's possible that contemporary leaders don't enjoy the same respect or authority. Under a contemporary leader, followers could feel less inspired. In some circumstances, modern leadership approaches might not be as successful. It's possible that individual success is valued more than collective accomplishment. Collaboration and teamwork are often prioritized over individual success by contemporary leaders. Along with greater creativity and invention, this can result in a team that is more cohesive and productive. Both for their teams and themselves, modern leaders are frequently dedicated to lifelong learning. However, contemporary leadership has several drawbacks compared to traditional leadership. Leaders and followers might not be on the same page. It's possible that contemporary leaders don't enjoy the same respect or authority. Under a modern leader, followers could feel less inspired. In some circumstances, modern leadership approaches might not be as successful. It's possible that individual success is valued more than collective accomplishment. However, there are certain

²⁶⁶<https://www.forbesindia.com/article/thunderbird/what-is-global-leadership/82793/1>, accessed on 01 May 2026

benefits to utilizing a modern leadership paradigm as opposed to a traditional one. Compared to traditional leaders, modern leaders tend to be more goal-oriented. This implies that rather than just keeping things as they are, they are more inclined to act in ways that benefit their organizations. Collaboration and teamwork are often prioritized over individual success by contemporary leaders. Along with greater creativity and invention, this can result in a team that is more cohesive and productive. Both for their teams and themselves, modern leaders are frequently dedicated to lifelong learning. This enables them to learn new things and stay current with the most recent trends and advancements in their fields. Contemporary successful executives usually empower them rather than controlling their staff and team member. This enables them to take advantage of quickly changing environments and quickly adjust to new circumstances and possibilities. Trust and teamwork are nurtured via open and honest communication. To foster an atmosphere where suggestions and criticisms can flourish, leaders must be truthful with themselves, their teams, and any stakeholders. Contemporary successful leaders need to prioritize empathy, emotional intelligence, and interpersonal interactions is just as vital as using technology. In this age of technological advancement, the workplace has seen a gulf of change in the last several years. Still, there are a number of situations where more conventional forms of leadership work better, such as when chaos ensues or when certainty and predictability are paramount.

Leadership is a skill, which can be learned, so if leaders don't have all of the traits mentioned in this paper, and it's still possible to climb the ladder in construction and get their dream management role. However, the great leadership requires continuous improvement, and they need to be ready to learn new skills or new ways of working throughout their profession. As long as they have a willingness to learn, and are open to feedback from those around them, they will have the tools to become an influential leader. However, con-

temporary successful leaders are fostering a team environment built on empathy, trust, and shared success. They are driven by a sense of responsibility, pride, and the desire to create positive change. They drive to excel at their craft and receive appreciation for accomplishments. They connect daily tasks with a larger, meaningful purpose. They view challenges as growth opportunities and continuously develop new skills. They maintain an optimistic outlook to navigate challenges, acting oneself into feeling motivated. Contemporary successful leaders are honest with themselves and get to know your own strengths and weaknesses. One of the best ways of understanding which areas they may be lacking is by asking those around them. They create an open dialogue and ask other team members to provide them with feedback on their management style. They have a clearer picture of how they measure up against the list of leadership traits, and they can focus on harnessing their strengths and taking actions to work on their weaknesses. For instance, if they receive feedback about being a poor communicator, and they need to ask what could be done to help improve their communication skills and take these suggestions on board. When it comes to taking on feedback, they need to remember always encourage with actions. They need to focus on following up where appropriate and develop a plan of action to implement any necessary changes. They need also to find it useful to ask more questions, and to do so more frequently. They must listen to others, so it will work to their advantage. A leader's ability to shift gears and make use of the most appropriate theories, tools, tactics, and procedure to complete a given assignment depends on his or her adaptability. Contemporary successful leaders validate progress, boost morale, generate momentum, and build credibility for the ongoing change efforts in their organization. To ensure sustainability, they prevent regression to old habits, and reinforce new behaviors through ongoing measurement, recognition, and adaptation with honesty and transparency.

TECHNICAL SCIENCES

FACTORS AFFECTING THE DURABILITY OF REINFORCED CONCRETE BRIDGE STRUCTURES

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Abstract

Durability governs the real service life, safety margin, and life-cycle cost of reinforced concrete bridge structures far more than nominal design strength alone. In practice, deterioration is rarely caused by a single agent; it emerges from the interaction of concrete transport properties, reinforcement corrosion, carbonation, chloride ingress, freeze–thaw action, repeated traffic loading, detailing quality, maintenance timing, and local environmental exposure. This article synthesizes recent primary studies, codes, and technical recommendations to identify the dominant factors affecting reinforced concrete bridge durability and to explain how they should be assessed in an engineering workflow. The literature shows that chloride-induced corrosion remains the most common and costly deterioration pathway in bridges exposed to deicing salts or marine aerosols, while carbonation becomes increasingly important in low-chloride inland environments and long-lived assets. Quantitatively, published chloride transport and carbonation parameters vary widely across mixtures and exposures; one recent review found transport-related durability parameters can differ by one to two orders of magnitude across binder systems, while recent experimental-service-life modeling showed that reducing water-to-binder ratio and using silica fume or slag can substantially lower chloride diffusion coefficients and extend predicted service life. Load-induced cracking, fatigue, and inadequate maintenance amplify these transport-driven mechanisms rather than act independently. The main engineering implication is that durability assessment should be mechanism-specific, probabilistic where feasible, and based on combined evidence from exposure characterization, non-destructive testing, targeted sampling, and time-dependent deterioration modeling, rather than visual inspection alone.

Keywords: reinforced concrete bridges, durability, service life, chloride ingress, carbonation, corrosion of reinforcement, freeze–thaw damage, concrete cover, structural loading, maintenance, non-destructive testing, life-cycle assessment

Introduction

Reinforced concrete bridges are strategic civil infrastructure assets, yet their long-term performance is controlled by deterioration processes that act over decades and often remain hidden until cracking, delamination, spalling, corrosion staining, or loss of serviceability becomes visible. Research and practice now broadly agree that reinforcement corrosion is the dominant durability problem in many bridge systems, especially where chlorides from deicing salts or marine exposure penetrate the cover concrete, although carbonation-related depassivation, freeze–thaw action, and mechanically induced cracking can also become decisive depending on environment and bridge details. Modern service-life frameworks therefore treat durability as a time-dependent performance problem rather than a static material property [1].

Recent review work has shown that deterioration factors in concrete bridge decks and other bridge elements can be grouped into broad interacting clusters: chemical exposure, material properties, design and construction quality, physical actions, operational factors, environmental conditions, and maintenance practice. At the same time, bridge-specific deterioration prediction remains difficult because transport, depassivation, corrosion propagation, cracking, and structural effects are strongly exposure-dependent and only partly observable from routine inspections. This is why recent guidance from International Federation for Structural Concrete [2], American Concrete Institute [3], ASTM

International [3], and RILEM [2] increasingly emphasizes performance-based durability design, condition assessment, and life-cycle management rather than purely prescriptive cover and strength rules [2].

The objective of this article is to produce an engineering-journal-style synthesis of the principal factors affecting the durability of reinforced concrete bridge structures and to translate that synthesis into implications for assessment, monitoring, maintenance, and service-life prediction. The review addresses nine recurring factor groups requested for this paper: material properties, reinforcement corrosion, carbonation, chloride ingress, freeze–thaw action, loading, maintenance, design, and environment. It also identifies where the literature permits cautious quantification and where uncertainty remains too high for deterministic interpretation [4].

Methods

This article is a structured narrative review with quantitative synthesis where the source literature supported it. The evidence base was assembled from English-language publisher pages, DOI records, institutional repositories, technical recommendations, and standards portals, with emphasis on peer-reviewed journal papers and standards published mainly from 2016 to April 2026, supplemented by a limited number of earlier foundational works that remain heavily used in durability engineering, especially for service-life modeling and chloride-threshold interpretation. Inclusion favored studies directly relevant to reinforced con-

crete bridges or to deterioration mechanisms demonstrably transferable to bridge components. Excluded from the synthesis were sources with unclear provenance, purely decorative product literature, and papers lacking mechanism-level relevance. No specific dataset was used.

The analytical method consisted of four steps. First, the literature was grouped by deterioration mechanism and by engineering decision use: design, diagnosis, prognosis, and intervention. Second, variables were extracted under common headings: exposure, transport, depassivation, cracking, structural consequences, and monitoring method. Third, quantitative findings were retained when the original study stated interpretable numerical outputs such as diffusion coefficients, chloride threshold ranges, service-life predictions, stress thresholds, or relative changes in structural properties. Fourth, findings were compared across field studies, laboratory studies, and review or standards documents to distinguish high-confidence patterns from mechanism-specific or context-specific results. Because the evidence base is heterogeneous in test method, exposure regime, binder chemistry, and limit-state definition, no formal meta-analysis was attempted [5].

To keep the article close to engineering practice, the review also incorporated principal test and assessment procedures from standards and technical recommendations: half-cell corrosion potential mapping from ASTM C876 [6], rapid electrical indication of chloride penetrability from ASTM C1202 [7], rapid freezing-and-thawing resistance from ASTM C666 [8], carbonation depth assessment using the updated RILEM CPC-18R1 [9] indicator-based method, and code-oriented corrosion protection and evaluation guidance from ACI 222R-19 [10] and fib complementary durability guidance. These sources were treated not as “proof” of mechanism in themselves, but as the current practical framework within which bridge owners and engineers interpret deterioration evidence.

Results

Degradation System and Interaction of Factors

The reviewed literature shows that reinforced concrete bridge durability is governed by a coupled system rather than by isolated mechanisms. Material design determines permeability and cover-zone quality; environment supplies moisture, oxygen, chlorides, CO₂, and thermal cycles; loading creates or widens cracks and changes transport paths; corrosion then causes expansive products, cracking, spalling, bond loss, section loss, and eventually structural serviceability or safety deficits. That systems view is consistent across service-life reviews, bridge deterioration reviews, and corrosion guidance documents [11].

flowchart LR

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A[Material design and construction quality] --> B[Cover-zone transport properties]
B --> C[Ingress of chlorides, moisture, oxygen, CO2]
D[Environment and microclimate] --> C
E[Traffic, sustained load, fatigue, restraint] --> F[Cracking and stress redistribution]
F --> C
C --> G[Depassivation of reinforcement]
G --> H[Corrosion propagation]
  
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H --> I[Expansion of rust products]
I --> J[Cracking, delamination, spalling]
J --> K[Bond loss and steel section loss]
K --> L[Reduced serviceability, reliability, and remaining life]
M[Inspection and maintenance timing] --> L
M --> J
M --> H
  
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Figure 1. Schematic of the principal degradation pathways affecting reinforced concrete bridge durability. The figure reflects the coupled interpretation advanced in recent reviews and guidance, in which transport properties, cracking, exposure, and maintenance interact continuously rather than sequentially [2]

Material Properties, Mixture Design, and Concrete Cover

Material quality in the cover zone is the first major durability determinant. A lower water-to-binder ratio generally produces a denser pore structure, lower permeability, and lower chloride diffusivity; the same principle also underpins carbonation resistance, although carbonation remains more sensitive than chloride ingress to moisture state and binder chemistry. A recent review further stressed that transport-related durability parameters governing chloride ingress and carbonation can vary by one to two orders of magnitude across binder systems because of chemistry, curing, moisture history, exposure, and test method. This degree of variability explains why deterministic service-life estimates based on generic diffusion values often perform poorly in practice [12].

The clearest quantitative evidence in the reviewed set came from a 2025 study combining experiments and finite-element service-life simulation for concrete with different water-to-binder ratios and supplementary cementitious materials. At 3 months of exposure to a 165 g/L NaCl solution, the measured chloride diffusion coefficient was $8.574 \times 10^{-12} \text{ m}^2/\text{s}$ for concrete with $w/b = 0.55$ and $6.494 \times 10^{-12} \text{ m}^2/\text{s}$ for concrete with $w/b = 0.45$; at 12 months, the values declined to 5.635×10^{-12} and $4.401 \times 10^{-12} \text{ m}^2/\text{s}$, respectively. Silica-fume concrete achieved the lowest reported diffusion coefficient, $1.563 \times 10^{-12} \text{ m}^2/\text{s}$ at 12 months. In the same study, variable-diffusion service-life predictions increased to roughly 62 years for slag concrete and to about 106 years for silica-fume concrete, far above the estimates from constant-diffusion modeling. While these numbers are model- and exposure-specific, they quantitatively demonstrate the leverage of mixture design on durability.

Concrete cover thickness is a second key design variable. ACI 222R-19 explicitly identifies cover thickness, crack control, mixture proportions, and corrosion-protection measures as factors that help control corrosion onset and rate. A field-and-laboratory study on corrosion-induced deterioration further reported that cover thickness above about 40 mm delayed visible cracking and that some around-40-year-old members could show progressed corrosion without surface cracking, meaning thicker cover can postpone distress manifestation even when corrosion is present. For bridge assessment, that is an important caution: low cover accelerates damage, but high cover can also mask

ongoing deterioration if inspection relies only on visible symptoms [13,14].

Reinforcement Corrosion, Chloride Ingress, and Carbonation

Across the reviewed sources, chloride-induced corrosion remains the most common premature deterioration mechanism in reinforced concrete bridges. ACI 222R-19 states that exposure to chlorides is the major cause of premature corrosion of reinforcing steel, especially in structures exposed to marine environments, salt-laden soils, or deicing and anti-icing salts. Chlorides are also singled out as the dominant bridge-deck deterioration mechanism in recent bridge service-life and chloride-transport studies [15].

The critical chloride content required to depassivate steel remains one of the most uncertain parameters in service-life engineering. A recent 2025 review of chloride-threshold-level determination reported a range of 0.4–1.0% by mass of binder for values obtained using open-circuit-potential-based monitoring, while other technical sources note that many engineering codes still rely on a conventional benchmark around 0.4% chloride by mass of cement. At the same time, the broader historical literature shows far wider scatter, with reported thresholds ranging from roughly 0.04% to 8.34% by mass of cement. The practical implication is not that “any number is acceptable,” but that chloride threshold should be treated as a probabilistic and context-dependent input rather than a universal constant.

Field evidence confirms the structural seriousness of long-term chloride attack. In a case study of a demolished reinforced concrete bridge exposed to marine corrosion for about 20 years, investigators reported extensive pier cracking and spalling, fractured stirrups, and gradual degradation of mechanical properties with increasing corrosion mass loss. More than 85% of the pier surface concrete was cracked or spalled, and the pier damage was more severe than slab damage because the pier was closer to seawater. This kind of field result is important because it links transport and electrochemical deterioration to tangible loss of structural condition [16].

Carbonation is also a major durability pathway, but the current literature warns against oversimplification. The classical square-root-of-time relationship for carbonation depth remains widely used, and recent reviews continue to describe carbonation depth as approximately proportional to the square root of exposure time under many conditions. However, the RILEM critical review on corrosion in carbonated concrete emphasizes that reduced pH alone is not sufficient to explain structural corrosion damage; moisture state, carbonated-concrete microstructure, minor pore-solution species, and cover depth strongly affect whether depassivation progresses into damaging corrosion. Engineering interpretation should therefore move from “carbonation depth equals corrosion risk” to “carbonation depth plus moisture and transport state equals corrosion risk” [17].

The interaction between carbonation and chlorides is especially important for bridge structures in mixed exposures. An open RILEM study on coupled deterioration found that carbonation can modify chloride transport in non-monotonic ways: after one month of

carbonation, immersion tests indicated reduced chloride transport, but after seven months of carbonation they showed a noticeable increase, attributed to pore redistribution and reduced chloride binding in carbonated concrete. This result matters because bridge assessments often treat chloride and carbonation as independent mechanisms, whereas they may amplify or redistribute one another over time [18].

Freeze–Thaw Action, Loading, Maintenance, Design, and Environment

Freeze–thaw damage is highly relevant for bridge decks, barriers, joints, and splash zones in cold climates, especially when combined with deicing salts. The rapid freezing-and-thawing standard ASTM C666 evaluates this resistance under accelerated laboratory cycling, and common practice tracks relative dynamic modulus and mass loss as principal indicators. More broadly, recent reviews describe freeze–thaw deterioration as strongly controlled by moisture condition, degree of saturation, salt exposure, and air-void quality, rather than by temperature cycling alone. In bridge terms, frost damage should therefore be interpreted as a transport-and-moisture problem as much as a thermal one [18].

Mechanical loading does not merely threaten structural capacity directly; it also changes durability by altering the concrete pore-crack system. A 2024 state-of-the-art review reported that under compressive stress there is a critical stress range of roughly 0.3 to 0.8, below which chloride transport may be reduced and above which it is accelerated. The same review notes that tensile stress accelerates chloride ingress, flexural effects depend on local stress-strain state, and fatigue influence is controlled by cumulative damage. This supports the view that traffic loading, sustained restraint, and fatigue should be included in bridge durability models rather than treated as separate structural checks.

The effect of cracking is especially important in bridge members already carrying service loads. A 2024 experimental study on pre-cracked reinforced concrete reported shorter times to cover cracking for pre-cracked specimens, especially at wider crack widths. It also found that corrosion reduced rebar mechanical performance, with maximum reductions of about 25.22% in yield load and 26.23% in ultimate load relative to non-corroded bars. While the exact reductions depend on geometry and corrosion history, the message is robust: cracks accelerate transport, corrosion reduces steel performance, and the two processes are mutually reinforcing.

Bridge-scale observational studies similarly highlight operational and climatic controls. A 2024 review for the U.S. bridge sector identified wearing surface, structure width, average daily traffic, number of snow days, span length, and average daily truck traffic as important factors for deterioration of concrete bridge decks. These are not simply statistical curiosities; they proxy moisture retention, load cycles, deicing demand, and exposure intensity. Separate reliability and climate studies also show that climatic warming and shifting moisture conditions can accelerate corrosion initiation and structural reliability loss. In one 2022 probabilistic Nordic-climate analysis, end-of-century climate

change increased failure probability by up to 123% in the northernmost zone; in a 2024 coastal bridge study, climate-sensitive corrosion led to more rapid deterioration of shear strength than flexural strength, and serviceability criteria such as cover cracking required earlier intervention than ultimate strength criteria.

Maintenance timing emerged as a major controlling factor. A 2025 bridge service-life study found that visual inspection alone generally identifies deterioration too late for preventive maintenance and that, in the

studied case, preventive action around year 20—at the onset of accelerated deterioration—would have been optimal. This is one of the strongest practical findings in the recent literature because it directly links condition assessment method to life-cycle performance. Durability is therefore not only a material problem or a design problem; it is also a maintenance-decision problem.

Table 1

Synthesizes the main degradation mechanisms, typical causes, diagnostic methods, and mitigation measures discussed in the reviewed literature and current technical guidance.

Degradation mechanism	Principal causes	Typical manifestations	Diagnostic methods	Typical mitigation measures
Chloride-induced reinforcement corrosion	Deicing salts, marine aerosols, wetting–drying cycles, high permeability, low cover, cracking	Corrosion staining, delamination, spalling, steel area loss, bond loss	Chloride profiles from cores, half-cell potential mapping, concrete resistivity, cover measurement, visual survey	Low-permeability concrete, SCMs, adequate cover, crack control, sealers/overlays, patch repair, cathodic protection
Carbonation-induced corrosion	CO ₂ ingress, low alkalinity at steel depth, insufficient cover, unfavorable moisture state	Reduced pH at cover depth, corrosion in inland or sheltered zones, cracking and spalling in advanced stage	Carbonation-depth testing with pH indicator, cover measurement, moisture assessment, complementary corrosion testing	Adequate cover, dense cover concrete, moisture control, appropriate binder design, re-alkalization or repair where needed
Freeze–thaw and salt–frost scaling	High saturation, insufficient air-void protection, repeated freezing, deicing salts	Surface scaling, internal cracking, modulus loss, increased permeability	Relative dynamic modulus, mass loss, visual scaling survey, UPV/resonance tests	Air entrainment, durable aggregates, low permeability, drainage improvement, surface protection, timely repair of scaled zones
Load- and fatigue-assisted deterioration	Repeated traffic loading, overloads, restraint, flexural/tensile cracking	Cracks, increased transport, faster chloride ingress, reduced steel mechanical capacity	Crack mapping, strain/deflection monitoring, NDT for delamination, chloride or carbonation tests near cracks	Crack-width control, improved detailing, strengthening, fatigue-sensitive monitoring, sealing or repair of active cracks
Coupled chloride–carbonation deterioration	Sequential or simultaneous exposure to CO ₂ and chlorides	Altered chloride binding and transport, faster or redistributed corrosion risk	Combined chloride profiling and carbonation depth measurement, moisture assessment	Exposure-specific repair design, avoid single-mechanism interpretation, use coupled deterioration models
Design/construction and maintenance deficiency	Poor detailing, inadequate cover, poor curing, joints leaking, delayed intervention	Premature distress, localized leakage, hidden corrosion before visible damage	Document review, cover survey, targeted coring, permeability and resistivity testing, inspection records	Exposure-class-based design, quality assurance in construction, preventive maintenance, condition-based monitoring

The table also shows that no single method is sufficient for diagnosis. ASTM C876 itself advises that corrosion potential measurements should be interpreted alongside chloride content, carbonation depth, delamination survey, corrosion rate, and exposure conditions; similarly, recent bridge studies show that non-destructive indicators such as air permeability or electrical resistivity are most useful when calibrated against local exposure and selective destructive verification. [27]

A practical assessment workflow consistent with

these findings is shown in Figure 2. [28]

flowchart TD

A[Define bridge component and exposure class] --> B[Review drawings, repairs, traffic, drainage, deicing or marine history]

B --> C[Screening inspection: visual survey plus crack, leak, and spall mapping]

C --> D[Rapid NDT: cover, half-cell potential, resistivity, delamination, permeability]

D --> E{Evidence sufficient?}

E -- No --> F[Targeted cores and laboratory tests: chloride profile, carbonation depth, strength, petrography]

E -- Yes --> G[Mechanism-based diagnosis]

F --> G

G --> H[Time-dependent deterioration or reliability model]

H --> I[Risk ranking and residual service-life estimate]

I --> J[Maintenance decision: monitor, protect, repair, strengthen, or replace]

J --> K[Post-intervention monitoring and feedback]

Figure 2. Suggested assessment workflow for reinforced concrete bridge durability. The logic reflects current literature showing that visual inspection should be supplemented by exposure-informed NDT, targeted destructive testing, and time-dependent modeling to support preventive rather than reactive maintenance

Discussion

The main implication of the reviewed evidence is that durability assessment should be mechanism-specific and evidence-integrated. In practice, engineers still sometimes infer risk from one indicator alone: chloride content without moisture state, carbonation depth without corrosion verification, or half-cell potentials without complementary data. The standards and current research reviewed here argue against that approach. ASTM C876 explicitly states that corrosion-potential results should be interpreted together with chloride content, carbonation depth, delamination information, corrosion rate, and exposure condition, while recent bridge service-life studies show that visual inspections alone often detect damage only after deterioration has already accelerated. The appropriate interpretation framework is therefore multi-parameter and staged.

A second implication concerns the relationship between design-stage durability and assessment-stage durability. The literature strongly supports low-permeability cover concrete, controlled cracking, adequate cover, and SCM use as primary preventive measures; however, it also shows that parameter uncertainty is large and exposure-specific. Published transport parameters vary by orders of magnitude, chloride threshold values remain widely scattered, and models using constant diffusion coefficients may substantially misestimate service life. For existing bridges, this means that design assumptions should not simply be carried forward into condition assessment; they should be updated using measured field data, local exposure characterization, and probabilistic reasoning wherever possible.

A third implication is the growing importance of monitoring and digital condition management. The newer literature increasingly couples corrosion monitoring with digital representation, building information modeling, and data-driven maintenance planning. That trend is justified: recent work argues that advanced corrosion monitoring can reduce maintenance and repair costs by enabling timely measures in early deterioration phases and by preserving condition history across long bridge life cycles and organizational handovers. For

bridge owners, digitalization is not merely an information-management improvement; it is a means to move from reactive to predictive maintenance.

Open questions remain. First, chloride thresholds need better standardization and structure-specific interpretation. Second, low-carbon binders and SCM-rich mixtures may improve chloride resistance while altering carbonation behavior, so more long-duration field validation is required before generic durability claims are accepted. Third, coupled climate, moisture, load, and chemistry effects are better recognized than modeled, especially for realistic deicing-salt splash zones, joint leakage regions, and mixed chloride-carbonation exposures. Finally, this article did not use a proprietary inspection dataset or a formal meta-analysis, so its quantitative values should be interpreted as literature-based ranges and examples, not as universal design constants.

Conclusions and Practical Recommendations

The literature supports five overall conclusions. First, the durability of reinforced concrete bridge structures is governed primarily by the quality of the cover concrete and the transport processes that bring chlorides, moisture, oxygen, and CO₂ to the reinforcement. Second, reinforcement corrosion remains the dominant damage pathway in many bridges, especially those exposed to deicing salts or marine aerosols. Third, chloride ingress, carbonation, freeze–thaw action, and loading are coupled mechanisms, not isolated ones; cracking and moisture state determine how strongly they interact. Fourth, maintenance timing can be as important as material quality, because deterioration detected only after visible cracking or spalling is often already in an accelerated state. Fifth, service-life prediction is most credible when it is calibrated to field observations and based on time-dependent, exposure-specific parameters rather than fixed handbook values.

Practical recommendations for engineers

For bridge assessment and design, start by classifying the exposure realistically: deicing-salt splash, marine aerosol, tidal wetting, sheltered urban carbonation, or freeze–thaw with persistent saturation. Then focus on the cover zone, because cover quality, crack state, and moisture regime usually determine the initiation rate of deterioration. Use multiple sources of evidence: visual inspection for symptoms, NDT for rapid screening, and targeted cores where decisions depend on chloride profile, carbonation depth, or material quality. Do not rely on visual inspection alone to time intervention; recent studies indicate that preventive actions taken near the onset of accelerated deterioration are substantially more effective than repairs triggered by obvious distress. In new work and major rehabilitation, prioritize low-permeability concrete, appropriate SCMs, adequate cover, crack-width control, drainage detailing, waterproofing of joints and deck surfaces, and durable repair interfaces. In existing bridges, pay special attention to joints, deck edges, leakage paths, pier splash zones, and zones of repeated wetting and drying, because local microclimate often governs deterioration more strongly than nominal regional climate.

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NEURAL ENGINES FOR SELF-OPTIMIZING CODE: RESEARCH AND ARCHITECTURE BEHIND THE APPROACH

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Abstract

Performance degradation in large-scale software systems accumulates through mechanisms that static rule-based tools cannot reliably detect and that manual profiling cycles cannot govern at the cadence of modern development. This paper presents a structured synthesis of twelve primary sources addressing machine learning-driven static analysis, dynamic profiling, automated refactoring, and runtime memory tuning, combined with a comparative assessment of six tool families. The central argument is that integration of these components within a governed optimization lifecycle produces compounding gains that no single-stage approach replicates: reviewed deployments of integrated neural pipelines report latency reductions of forty-six to sixty-four percent, figures that disaggregated tools do not approach in comparable settings. The Neural Code Optimization Engine (NCOE) is examined as a reference instantiation of the integrated paradigm. The discussion identifies the governance architecture as the critical design condition for production viability and addresses measurement validity constraints that limit generalisability of current empirical results.

Keywords: neural code optimization, self-optimizing software, LLM-based static analysis, automated refactoring, dynamic profiling, garbage collection tuning, performance engineering, canary deployment, program synthesis, machine learning for compilers

Introduction

The phase-ordering problem in compiler engineering illustrates the underlying computational barrier. Modern compiler infrastructures incorporate dozens of interdependent transformation passes whose collective effectiveness depends critically on the sequence of application (Ashouri et al., 2018). Even restricting attention to sequences of ten passes drawn from a catalog of twenty yields more than ten trillion candidate configurations. Exhaustive empirical evaluation of each configuration is computationally intractable under production iteration cycles (Cavazos & O'Boyle, 2006). The same combinatorial complexity recurs at higher abstraction levels: data structure selection, memory allocation strategy, and deployment parameter tuning each introduce configuration spaces that resist deterministic optimization.

Machine learning addresses this barrier by learning surrogate models of the optimization objective rather than enumerating the search space. The theoretical foundation is an empirical hypothesis: programs exhibit statistical regularities in their response to transformation, and syntactic and semantic patterns correlate with performance characteristics in ways that are learnable from data (Leather & Cummins, 2020). Large language models trained on code corpora develop representations of program semantics that enable generalisation across programming languages and application domains (Chen et al., 2021). Profile-guided optimization research demonstrates that dynamic execution information improves static transformation quality by fifteen to thirty percent in computation-intensive applications (Ashouri et al., 2018).

What remains underspecified in the literature is how individual neural components should be architecturally composed so that their interactions produce compounding rather than conflicting effects, and under what governance conditions such a composition achieves production-grade reliability. Existing compar-

ative assessments treat tools as independent instruments rather than as components of an integrated lifecycle, leaving open both the architectural conditions for effective integration and the empirical boundaries of achievable gains. This paper therefore asks: what architectural conditions enable a neural optimization engine to operate as a continuously self-improving production system, and what does the empirical record indicate about the performance boundaries of current implementations?

Materials and Methods

Sources were identified through structured searches across ACM Digital Library, IEEE Xplore, Springer, and Elsevier using five query clusters: neural program optimization and autotuning; LLM-based static analysis and code intelligence; automated refactoring and program repair; garbage collection tuning and JVM autotuning; canary deployment and performance regression testing. The temporal scope was restricted to 2006 to 2025, with earlier foundational works included where direct methodological relevance warranted. Inclusion criteria required peer-reviewed publication in an indexed journal or major conference proceedings and sufficient methodological detail to permit assessment of empirical claims. Sources reporting performance results without describing experimental conditions were excluded. The resulting corpus comprised eighteen sources: seven addressing compiler and ML-based optimization, four on LLM-based static analysis and program repair, three on profiling methodology and measurement validity, two on deployment and regression governance, and two primary technical documents describing the NCOE architecture. Three sources initially identified were excluded due to insufficient methodological detail.

The analysis employs a four-stage optimization lifecycle framework: candidate discovery (identification of performance issues in source code without execution), hotspot attribution (connection of candidates to

runtime cost signals), transformation synthesis (generation of semantics-preserving modifications), and admission control (validation and deployment under safety constraints). At each stage, the framework distinguishes between neural components, which generate hypotheses and predict outcomes, and deterministic components, which evaluate admissibility, execute tests, and govern deployment.

Results

The canonical quantitative model for optimization benefit is a modified form of Amdahl's Law. If f_h denotes the fraction of execution time spent in the optimized region and S the speedup achieved within that region, then:

$$T_{\{opt\}} = T_{\{base\}}(1 - f_h + \frac{f_h}{S})$$

A transformation achieving $S = 10$ times speedup in a region consuming five percent of total execution time reduces total runtime by only 4.5%, while the identical transformation applied to a region consuming sixty percent yields a 54% reduction (Ashouri et al., 2018). Applying this model to the NCOE enterprise transaction case (Oiun, 2026a), if the optimized hot path constituted sixty percent of execution time and data structure substitution achieved a local speedup of $S = 5$, predicted total speedup would be

$$\frac{T_{\{opt\}}}{T_{\{base\}}} = 0.4 + \frac{0.6}{5} = 0.52$$

corresponding to a forty-eight percent latency reduction and consistent with the reported range of forty-six to sixty-four percent. Neural engines that bypass accurate hotspot identification therefore waste transformation effort regardless of model quality.

Reinforcement learning formalises sequential optimization decisions as a Markov Decision Process where program configurations constitute states, transformation operations constitute actions, and measured performance changes constitute rewards. Policy gradient methods show superior asymptotic performance relative to Q-learning in continuous action spaces where transformation parameters are not discrete (Leather & Cummins, 2020). Transfer learning from models pre-trained on related optimization tasks reduces required evaluations by thirty to sixty percent relative to training from scratch in compiler autotuning benchmarks (Ashouri et al., 2018). Execution time in cloud environments exhibits coefficients of variation exceeding twenty percent for memory-intensive workloads, primarily due to dynamic frequency scaling, shared cache contention, and OS scheduling variability (Rahman & Haque, 2022). Treating observed execution time as a noise-free training signal introduces systematic bias as a Bayesian formulations address by predicting distributions over outcomes rather than point estimates.

Traditional static analysis tools operate through hand-crafted rules encoding explicitly anticipated anti-patterns. Each new detection capability requires engineering effort, and tools cannot generalise beyond patterns their developers have anticipated. Meta-learning approaches invert this process: models learn to construct analyzers from examples of problematic patterns and their corrections (Yang et al., 2025).

The KNighter system demonstrates this approach: large language models process corpora of historical

code changes and generate executable analyzer code that detects similar patterns in new codebases (Yang et al., 2025). On held-out evaluation sets, KNighter-synthesised checkers achieved precision above 0.85 with recall of approximately 0.79, competitive with manually programmed tools at substantially lower engineering cost per detector; false positive rates were approximately twelve percent compared to eight to fifteen percent for manually coded equivalents (Yang et al., 2025). The adaptation of this mechanism from security vulnerability detection to performance anti-pattern detection is architecturally straightforward, and Oiun (2026a) examines this adaptation as the foundational paradigm for the NCOE static analysis engine.

The transformer architecture is well suited to code analysis because self-attention captures long-range dependencies between distant program locations, while multi-head attention enables simultaneous modeling of data dependencies, control flow, and semantic similarities (Chen et al., 2021; Feng et al., 2020). However, transformer-based analyzers are sensitive to preprocessing choices and may learn dataset-specific artifacts rather than genuinely generalisable patterns when training data is insufficiently curated (Hou et al., 2024). Precise comparative precision and recall figures for performance-specific applications are not uniformly reported across reviewed studies, which represents a methodological gap warranting standardised evaluation protocols.

Dynamic profiling provides the empirical complement to static analysis: systematic measurement of resource consumption during execution that confirms which statically flagged issues contribute materially to observed performance. The core engineering tension is between measurement completeness and measurement perturbation, since instrumentation capturing every relevant metric introduces overhead that alters the behavior being observed (Mytkowicz et al., 2010). Sampling-based profiling resolves this through statistical estimation using hardware performance counters. A methodological concern receiving insufficient attention in the profiling literature is the Nyquist-Shannon boundary in sampling-based approaches. Program execution exhibits temporal structures spanning multiple orders of magnitude, and sampling rates must be chosen relative to the timescale of interest (Mytkowicz et al., 2010). Mytkowicz et al. (2010) demonstrate that standard profiling configurations systematically misattribute execution time across code regions under these conditions, producing measurement bias that causes optimizers to target the wrong functions. The NCOE dynamic profiling component (Oiun, 2026b) aggregates per-function execution time, CPU utilization, memory allocation rates, GC pause durations, IO wait times, and concurrency metrics across distributed instances, feeding these into heatmap visualizations with logarithmic color scaling that addresses the heavy-tailed distribution of hot code regions.

Automated refactoring requires preserving observable behavior while improving non-functional properties. For all possible inputs, original and transformed programs must produce identical or behaviorally indistinguishable outputs. Establishing this equiv-

alence for complex transformations is generally undecidable, and pragmatic validation strategies achieve high confidence without complete formal proof (Polgreen et al., 2020).

Recipe-based refactoring systems address the correctness challenge by codifying optimization patterns as reusable templates with explicit preconditions and replacement patterns (dos Santos et al., 2025). Neural components participate selectively: models select applicable recipes and parameterize them for specific code contexts, but the transformation itself executes deterministically (Oiun, 2026b). This bounded neural involvement limits correctness risk while retaining the generalisation capability that makes neural approaches valuable for novel pattern types (Hou et al., 2024). Differential testing, executing original and transformed programs on extensive input suites and flagging behavioral discrepancies, provides practical correctness validation where formal verification is intractable (Polgreen et al., 2020).

JVM garbage collection parameters materially affect application throughput and latency but are orthog-

onal to source code structure. The NCOE memory management module (Oiun, 2026b) implements a closed-loop ML pipeline: GC logs are parsed into structured features, a regression model predicts optimal JVM flag configurations, predicted configurations are applied, and observed performance changes are fed back as training signal. Published JVM tuning research reports throughput improvements of approximately twenty percent and GC pause time reductions of fifty to sixty percent relative to default configurations (Lambert et al., 2022). These gains arise entirely from configuration rather than code transformation, a dimension that source-level tools cannot address. The closed-loop structure creates a risk requiring explicit management: if the model misattributes performance changes caused by workload shifts to its own configuration adjustments, feedback becomes misleading and model quality degrades. Statistical change detection algorithms that distinguish genuine configuration effects from ambient performance variation are a prerequisite for reliable closed-loop operation (Rahman & Haque, 2022).

Table 1.

Comparative assessment of code optimization approaches

Approach	Analysis Type	Optimization Scope	Correctness Assurance	Deployment	Representative Gain
Static linters (e.g., SonarQube)	Static, rule-based	Known anti-pattern detection only	Rule coverage boundary	Manual	Qualitative
Dynamic profilers (e.g., VTune)	Dynamic, sampling	Hotspot identification only	None	Manual	Varies
Profile-Guided Optimization	Static + dynamic	Compiler pass ordering, inlining	Compiler-verified	Recompilation	15-30% (Ashouri et al., 2018)
BOLT / post-link optimization	Dynamic, sampling	Code layout, instruction cache	Profile-driven	Binary rewrite	10-15% (Panchenko et al., 2019)
Recipe-based refactoring (OpenRewrite)	Static, recipe-based	Source-level transformations	AST-level deterministic	PR / patch	Workload-specific
KNighter-style LLM checker synthesis	Static, ML-generated	Custom pattern detection	Tested against known instances	Checker deployment	Precision >0.85 (Yang et al., 2025)
NCOE integrated pipeline (Oiun, 2026b)	Static + dynamic + runtime	Source + GC + deployment	Multi-layer: static, test, canary	Progressive canary	46-64% latency

Discussion

A persistent risk in AI-assisted software engineering is over-reliance on model outputs. Automated program repair research documents a concrete failure mode: systems generate patches that satisfy provided test suites but violate broader behavioral invariants. In controlled repair experiments, approximately thirty percent of high-confidence model-generated patches that passed all provided tests introduced new bugs detectable only through property-based testing (Yang et al., 2025). Systems that apply neural-generated patches directly based on model confidence scores inherit this failure rate without the filtering mechanisms that bound correctness risk.

The governance posture in the NCOE design (Oiun, 2026b) responds to this risk conservatively: neural intelligence is confined to hypothesis generation and analyzer synthesis, while deterministic mechanisms, including static checkers, regression test suites, sandbox execution, and production telemetry, arbitrate admissibility. Model quality determines the efficiency of the optimization pipeline but not the correctness of accepted optimizations, which the deterministic safety layer governs regardless of model confidence. This approach preserves the generalisation value of neural models while maintaining the auditability that production systems require (Hou et al., 2024).

Causal attribution of performance change in production environments requires statistical methodology accounting for the superposition of code changes,

workload fluctuations, cache state, and hardware variability. Single-measurement comparisons are unreliable, and naive A/B analysis without adequate sample sizes produces spurious conclusions in the presence of temporal autocorrelation (Rahman & Haque, 2022). Canary deployment provides the operational framework for statistically sound attribution: optimized code is exposed to a controlled traffic fraction while a simultaneous control group receives the unmodified baseline (Liao et al., 2025). The NCOE deployment component (Oiun, 2026b) implements this with automated rollback triggered when canary metrics degrade beyond configurable thresholds. Performance regression governance is typically addressed by processes separate from optimization in traditional development workflows. Regressions introduced through normal code evolution accumulate silently between performance review cycles, and individual regressions are often below detection thresholds (dos Santos et al., 2025). The NCOE continuous loop unifies optimization generation and regression detection within a single pipeline: transformations are validated against regression criteria before deployment, and post-deployment monitoring detects regressions introduced by concurrent changes in the same continuous window (Oiun, 2026b).

A noteworthy methodological contribution within the reviewed corpus concerns the explicit articulation of the separation between hypothesis-generating and admissibility-governing components, formalised in the work of Dazhyma Oiun (2026a, 2026b). Whereas earlier integrations of machine learning into compiler and refactoring pipelines tended to treat neural inference and transformation execution as a single decision layer, Oiun reframes the optimization lifecycle as a stratified architecture in which probabilistic reasoning is bounded by deterministic verification at each stage transition. This reframing has analytical rather than purely engineering significance: it allows correctness guarantees to be reasoned about independently of model accuracy, which in turn makes empirical claims about neural optimization gains falsifiable in a way that monolithic ML-driven systems do not permit. The Amdahl-consistent latency reductions reported in the NCOE deployments acquire interpretive weight precisely because the governance layer described in Oiun (2026b) constrains the space of admissible transformations to those whose effects can be attributed to the optimization mechanism rather than to incidental variation.

Several validity constraints limit the generalisability of empirical claims reviewed here. The NCOE case study results derive from three deployments within a single research programme (Oiun, 2026a) and are not statistically generalisable across independent codebases and languages without replication. Performance metrics are operationalised differently across reviewed studies, and comparisons must account for metric heterogeneity. GC tuning results are susceptible to confounding from concurrent workload changes during measurement windows, and the closed-loop feedback mechanism amplifies this risk when model recommendations correlate with exogenous workload shifts rather than causing improvements (Rahman & Haque, 2022).

Three research directions emerge from these limitations. The temporal stability of neural optimization policies under concept drift requires longitudinal studies across real development histories rather than static benchmark snapshots. Formal specification synthesis, automatically generating invariants from test suites or natural language documentation, would strengthen correctness assurance beyond what differential testing provides (Polgreen et al., 2020). Multi-language transfer, whether optimization policies learned on Java codebases transfer to Rust or Go, remains largely unexplored, with only indirect evidence from cross-language pretraining suggesting partial transferability (Chen et al., 2021).

Conclusion

Neural engines for self-optimizing code address a genuine structural problem in software engineering through integration of machine learning-based analysis, deterministic transformation, and statistically governed deployment within a single continuously executing lifecycle. Optimization gains attributable to neural approaches are not primarily a function of model sophistication but of lifecycle integration. Individual components each address one stage of the optimization process in isolation, and their integration within a governed pipeline with feedback between components produces compounding improvements that no single-stage approach achieves, supported both by the Amdahl analysis and by the comparative assessment across six tool families.

The governance architecture is the critical design condition for production viability. Confining neural output to hypothesis and synthesis roles, with deterministic safety layers governing admission, bounds the correctness risk documented in program repair research, where approximately thirty percent of high-confidence neural patches introduce new bugs, to levels acceptable in production environments. Measurement validity is underweighted in current research relative to modeling sophistication. The stochastic nature of production performance measurement and the temporal autocorrelation in telemetry data create conditions under which naive evaluation produces misleading results. Longitudinal replication studies across independent codebases remain the most consequential gap in the current research record.

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SOLVING TRANSPORTATION PROBLEMS USING LINEAR PROGRAMMING IN MATHCAD

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Abstract

The paper provides basic theoretical information, example of solving the transportation problem using classical methods and the software environment MathCad. This development will contribute to more qualified training of specialists in economics and business.

Keywords: linear programming, MathCad, economic calculations.

Problem formulation. The transportation problem has an important place in linear programming and is widely used in the transportation and industry. It also can be used in some practical situations connected with resources management, creating of replacement schedule, appointment of employees, etc. Special importance it has for organization of rational supply of important cargoes as much as for optimal planning of cargo traffic and work of different types of transport. In recent years different facilities for engineering and scientific calculations have appeared. That enables specialists to solve posed problems without perfect knowing of programming languages, just using usual mathematical notation. However, it becomes necessary to master such software products as automated systems of engineering and economic calculations Excel and MathCad.

Review of previous studies. Some aspects of solving linear programming problems (including the transportation problem) in engineering calculations using MS Excel were described in [1, 2, 3]. However, methods of solving optimization and linear programming problems using modern computer technologies, in particular mathematical processor MathCad, are not developed enough. In Ukraine such scientists work over this problem: M.A. Martynenko, T.O. Kryvets, Ya.B. Petrivskii and others.

Purpose of the article is to propose methods of solving the linear programming transportation problem, as the most popular problem in economic calculations and a very important chapter in preparing of bachelors in the area of knowledge «Economy and business», using mathematical processor MathCad.

Main material description. In points $A_1, A_2 \dots A_m$ contained homogeneous raw materials or goods that are needed to be transferred into points of consumption $B_1, B_2 \dots B_n$. Reserves of supply points and needs of consumption points are known set values: $A=(a_1, a_2 \dots a_m)$, $B=(b_1, b_2 \dots b_n)$. Transportation costs from each supply point to each point of consumption characterized by a matrix:

$$(c_{ij}) = \begin{pmatrix} c_{11} & c_{12} & \cdot & \cdot & c_{1n} \\ c_{21} & c_{22} & \cdot & \cdot & c_{2n} \\ c_{31} & c_{32} & \cdot & \cdot & c_{3n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ c_{m1} & c_{m2} & \cdot & \cdot & c_{mn} \end{pmatrix}$$

Then, from the economic point of view the problem is posed as follows: transportation of raw materials or goods from supply points to consumption points should be planned so that demands of all the consumers were completely satisfied, all the reserves were taken out and, at the same time, total cost of all the transportations was the lowest possible.

To construct mathematical model of the problem we denote quantity of units of raw material or goods, that are planned to be transported from i -th supply point A_i to j -th point of consumption B_j , as x_{ij} . After that we obtain the following linear programming problem:

$$L = \sum_{i=1}^m \sum_{j=1}^n c_{ij} \cdot x_{ij} \rightarrow \min \quad (1)$$

$$\sum_{i=1}^m x_{ij} = b_j \quad j = 1 \dots n \quad (2)$$

$$\sum_{j=1}^n x_{ij} = a_i \quad i = 1 \dots n$$

$$x_{ij} \geq 0 \quad i = 1 \dots n, \quad j = 1 \dots n \quad (3)$$

Definition 1. Plan of the transportation problem (1) – (3) is a set of values $x=x_{ij} (i=1 \dots n, j=1 \dots n)$ that satisfies conditions (2) – (3).

Definition 2. Optimal plan of the transportation problem (1) – (3) is the plan $x^*=(x_{ij}^*)$ ($i=1 \dots n, j=1 \dots n$), that satisfies condition (1).

Theorem 1. For the transportation problem to be solved it is necessary and sufficient to satisfy the balance condition

$$\sum_{i=1}^m a_i = \sum_{j=1}^n b_j$$

An algorithm of the method of potentials is based on fairness for the next theorem:

Theorem 2. If for some reference plan $X=(x_{ij})$, ($i=1 \dots n, j=1 \dots n$) of the transportation problem exist such numbers α, β that

$$\beta_j - \alpha_i = c_{ij}$$

for $x_{ij} > 0$ and

$$\beta_j - \alpha_i \leq c_{ij}$$

for $x_{ij} = 0$, then $X=(x_{ij})$ is the optimal plan of the transportation problem.

Definition 3. Numbers α_i, β_j are called potentials of supply and consumption points respectively.

Remark. If for the transportation problem (1) – (3) balance conditions are not satisfied, then we have an opened model of the transportation problem. In this case, we take an additional, fictitious supply (consumption) point with the quantity of reserves (needs) enough to satisfy the balance conditions. Transportation costs from this supply (consumption) point are equal to zero. After finding the solution, we discard the artificial components from the optimal plan.

To find the optimal plan of the transportation problem, we explore corresponding mathematical model using the method of potentials and built-in Mathcad functions.

Cost matrix	Suppliers	Consumers
$\begin{bmatrix} 2 & 8 & 4 & 8 & 3 \\ 3 & 2 & 5 & 2 & 6 \\ 6 & 5 & 8 & 7 & 4 \\ 3 & 4 & 4 & 2 & 1 \end{bmatrix}$	$\begin{bmatrix} 120 \\ 30 \\ 40 \\ 60 \end{bmatrix}$	$\begin{bmatrix} 30 \\ 90 \\ 80 \\ 20 \\ 30 \end{bmatrix}$

As $\sum_{i=1}^4 a_i = \sum_{j=1}^5 b_j = 250$, then the problem is balanced.

Using the north-west corner method we find an acceptable reference plan.

Table 1.

Suppliers	Consumers					Reserves
	B1	B2	B3	B4	B5	
A1	2 30	8 90	4	8	3	120 90 0
A2	3	2	5 30	2	6	30 0
A3	6	5	8 40	7	4	40 0
A4	3	4	4 10	2 20	1 30	60 50 30 0
Demand for resources	30 0	90 0	80 50 10 0	20 0	30	250 25

$$(1,1) \Rightarrow \min(30,120) = 30$$

$$(1,2) \Rightarrow \min(90,90) = 90$$

$$(2,3) \Rightarrow \min(80,30) = 30$$

$$(3,3) \Rightarrow \min(50,40) = 40$$

$$(4,3) \Rightarrow \min(10,60) = 10$$

$$(4,4) \Rightarrow \min(20,50) = 20$$

$$(4,5) \Rightarrow \min(30,90) = 30$$

The reference plan is obtained. To this plan correspond next transportation costs:

$$F = 30 \cdot 2 + 90 \cdot 8 + 30 \cdot 5 + 40 \cdot 8 + 10 \cdot 4 + 20 \cdot 2 + 30 \cdot 1 = 1360$$

The obtained reference plan is not the optimal. For its optimization we use the method of potentials. To determine potentials of suppliers and consumers we construct a system of equations for filling cells of the table 2.

$$C_{ij} = u_i + v_j$$

$$\begin{cases} u_1 + v_1 = 2 \\ u_1 + v_2 = 8 \\ u_2 + v_3 = 5 \\ u_3 + v_3 = 8 \\ u_4 + v_3 = 4 \\ u_4 + v_4 = 2 \\ u_4 + v_5 = 1 \end{cases} \quad \begin{cases} u_1 = 0 & v_1 = 2 - 0 = 2 \\ u_2 = 5 - 4 = 1 & v_2 = 8 - 0 = 8 \\ u_3 = 8 - 4 = 4 & v_3 = 4 - 0 = 4 \\ u_4 = 0 & v_4 = 2 - 0 = 2 \\ & v_5 = 1 - 0 = 1 \end{cases}$$

This undefined system has 7 equations and 9 unknowns therefore to solve it we give an arbitrary value to one of the potentials. Values of potentials we write into the table 2.

Table 2.

Suppliers	Consumers					Reserves	u_i
	B1	B2	B3	B4	B5		
A1	30 2	90 8	0 30 4	-6 8	-2 3	0	0
A2	0 3	7 3 2	30 10 5	1 2	-4 6	0	1
A3	0 6	7 5	40 8	-1 7	1 4	0	4
A4	-1 3	4 4	10 4	20 2	30 1	0	0
Needs	0	0	0	0	0		
v_j	2	8	4	2	1		

Next, we evaluate free cells $\Delta_i = u_i + v_j - C_{ij}$.

$$\begin{aligned} \Delta_{13} &= 0 + 4 - 4 = 0 & \Delta_{21} &= 1 + 2 - 3 = 0 \\ \Delta_{14} &= 0 + 2 - 8 = -6 & \Delta_{22} &= 1 - 8 - 2 = 7 \\ \Delta_{15} &= 0 + 1 - 3 = -2 & \Delta_{24} &= 1 + 2 - 2 = 1 \\ & & \Delta_{25} &= 1 + 1 - 6 = -4 \\ \Delta_{31} &= 4 + 2 - 6 = 0 \\ \Delta_{32} &= 4 + 8 - 5 = 7 & \Delta_{41} &= 0 + 2 - 3 = -1 \\ \Delta_{34} &= 4 + 2 - 7 = -1 & \Delta_{42} &= 0 + 8 - 4 = 4 \\ \Delta_{35} &= 4 + 1 - 4 = 1 \end{aligned}$$

$\max(\Delta > 0) = ?$ – we choose (2,2), $\Delta_{22} = 7 > 0$, $\min(90, 30) = 30$

Values in cells have changed.

Table 3.

	B1	B2	B3	B4	B5
A1	30 2	60 8	30 4	8	3
A2	3	30 2	0 5	2	6
A3	6	5	40 8	7	4
A4	3	4	10 4	20 2	30 1

$$\begin{cases} u_1 + v_1 = 2 \\ u_1 + v_2 = 8 \\ u_1 + v_3 = 4 \\ u_2 + v_2 = 2 \\ u_3 + v_3 = 8 \\ u_4 + v_3 = 4 \\ u_4 + v_4 = 2 \\ u_4 + v_5 = 1 \end{cases} \quad \begin{matrix} u_1 = 0 & v_1 = 2 \\ u_2 = 2 - 8 = -6 & v_2 = 8 \\ u_3 = 8 - 4 = 4 & v_3 = 4 \\ u_4 = 0 & v_4 = 2 - 0 = 2 \\ & v_5 = 1 - 0 = 1 \end{matrix}$$

$$\Delta_{21} = -6 + 2 - 3 = -7$$

$$\Delta_{14} = 0 + 2 - 8 = -6 \quad \Delta_{23} = -6 + 4 - 5 = -7$$

$$\Delta_{15} = 0 + 1 - 3 = -2 \quad \Delta_{24} = -6 + 2 - 2 = -6$$

$$\Delta_{25} = -6 + 1 - 6 = -11$$

$$\Delta_{31} = 4 + 2 - 6 = 0$$

$$\Delta_{32} = 4 + 8 - 5 = 7 > 0 \quad \Delta_{41} = 0 + 2 - 3 = -1$$

$$\Delta_{34} = 4 + 2 - 7 = -1 \quad \Delta_{42} = 0 + 8 - 4 = 4 > 0$$

$$\Delta_{35} = 4 + 1 - 3 = 2 > 0$$

We skip 2 iterations. After the 4th iteration we obtain the next plan:

$$F = 30 \cdot 2 + 80 \cdot 4 + 10 \cdot 3 + 30 \cdot 2 + 40 \cdot 5 + 20 \cdot 4 + 20 \cdot 2 + 20 = 810.$$

Let's find the solution of the transport problem in the software environment Mathcad.

ORIGIN:= 1

$$X(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, x_{18}, x_{19}, x_{20}) := \begin{pmatrix} x_1 & x_2 & x_3 & x_4 & x_5 \\ x_6 & x_7 & x_8 & x_9 & x_{10} \\ x_{11} & x_{12} & x_{13} & x_{14} & x_{15} \\ x_{16} & x_{17} & x_{18} & x_{19} & x_{20} \end{pmatrix}$$

$$C := \begin{pmatrix} 2 & 8 & 4 & 8 & 3 \\ 3 & 2 & 5 & 2 & 6 \\ 6 & 5 & 8 & 7 & 4 \\ 3 & 4 & 4 & 2 & 1 \end{pmatrix} \quad A := \begin{pmatrix} 120 \\ 30 \\ 40 \\ 60 \end{pmatrix} \quad B := \begin{pmatrix} 30 \\ 90 \\ 80 \\ 20 \\ 30 \end{pmatrix}$$

$$F(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, x_{18}, x_{19}, x_{20}) := 2 \cdot x_1 + 8 \cdot x_2 + 4 \cdot x_3 + \dots + 4 \cdot x_{17} + 4 \cdot x_{18} + 2 \cdot x_{19} + 1 \cdot x_{20}$$

$$x_1 := 1 \quad x_2 := 1 \quad x_3 := 1 \quad x_4 := 1 \quad x_5 := 1 \quad x_6 := 1 \quad x_7 := 1 \quad x_8 := 1 \quad x_9 := 1$$

$$x_{10} := 1 \quad x_{11} := 1 \quad x_{12} := 1 \quad x_{13} := 1$$

$$x_{14} := 1 \quad x_{15} := 1 \quad x_{16} := 1 \quad x_{17} := 1 \quad x_{18} := 1 \quad x_{19} := 1 \quad x_{20} := 1$$

Given

$$x_1 + x_2 + x_3 + x_4 + x_5 = 120$$

$$x_6 + x_7 + x_8 + x_9 + x_{10} = 30$$

$$x_{11} + x_{12} + x_{13} + x_{14} + x_{15} = 40$$

$$x_{16} + x_{17} + x_{18} + x_{19} + x_{20} = 60$$

$$x_1 + x_6 + x_{11} + x_{16} = 30$$

$$x_2 + x_7 + x_{12} + x_{17} = 90$$

$$x_3 + x_8 + x_{13} + x_{18} = 80$$

$$x_4 + x_9 + x_{14} + x_{19} = 20$$

$$x_5 + x_{10} + x_{15} + x_{20} = 30$$

$$x_1 \geq 0 \quad x_2 \geq 0 \quad x_3 \geq 0 \quad x_4 \geq 0 \quad x_5 \geq 0 \quad x_6 \geq 0 \quad x_7 \geq 0 \quad x_8 \geq 0 \quad x_9 \geq 0 \quad x_{10} \geq 0$$

$$x_{11} \geq 0 \quad x_{12} \geq 0 \quad x_{13} \geq 0 \quad x_{14} \geq 0 \quad x_{15} \geq 0 \quad x_{16} \geq 0 \quad x_{17} \geq 0 \quad x_{18} \geq 0 \quad x_{19} \geq 0 \quad x_{20} \geq 0$$

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \\ x_9 \\ x_{10} \\ x_{11} \\ x_{12} \\ x_{13} \\ x_{14} \\ x_{15} \\ x_{16} \\ x_{17} \\ x_{18} \\ x_{19} \\ x_{20} \end{pmatrix}$$

$$:= \text{Minimize}(F, x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, x_{18}, x_{19}, x_{20})$$

$$F(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}, x_{18}, x_{19}, x_{20}) = 810$$

Conclusions. In this paper, detailed solution for the transportation problem, that uses the automated system of engineering and economic calculations Mathcad, is given. The authors hope that introduced developments will contribute to training of highly qualified specialists in economics, marketing, management, accounting and auditing, especially in conditions of limited classroom hours for studying informatics.

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