ScienceInnovation
INTERNATIONAL SCIENTIFIC JOURNAL

ISSN:
2181-3337

INTERNATIONAL SCIENTIFIC JOURNAL

SCIENCE AND INNOVATION

VOLUME 5 / ISSUE 4

A:
CHEMISTRY
TECHNIQUE
ECONOMICS
PHYSICS AND
MATHEMATICS

APRIL 2026

International Scientific Journal
SCIENCE AND INNOVATION
Series A
Volume 5 Issue 4
April 2026

Tashkent 2026

ISSN: 2181-3337

International Scientific Journal SCIENCE AND INNOVATION. Series A volume 5 issue 4 – 281 p.

The collection contains scientific articles accepted for issue 4 for 2026 of the international scientific journal "Science and Innovation".

In this scientific journal, in the form of scientific articles, the results of scientific research conducted by professors and teachers of the Republic of Uzbekistan and international higher educational institutions, independent researchers, doctoral students, undergraduates were published. In addition to higher educational institutions, the journal also includes scientific articles by employees working in other research institutes, production organizations and enterprises of our region and republic.

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This issue of the journal is indexed in the international scientific databases Index Copernicus, eLibrary.ru, OpenAire, EuroPub, ZENODO and Google Scholar.

All articles were placed in the electronic scientific database of the journal (scientists.uz).

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PHYSICAL PROPERTIES OF MOLYBDENUM AND ITS OXIDES IN FILM FORMATION

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https://doi.org/10.5281/zenodo.19703632

Abstract. *This article examines the requirements of modern electronics, the need for new materials and technologies to meet these requirements, and the challenges of creating heat-resistant alloys, including refractory alloys. The solution to these problems was the production of film structures based on molybdenum oxide, followed by a study of their properties using electrical and optical methods.*

Modern electronics require materials that can withstand increasingly harsh operating conditions, including elevated temperatures and aggressive environments. Traditional alloys often fail to meet these stringent requirements because of their limited thermal stability and mechanical strength. This challenge has driven the search for novel materials and advanced technologies capable of delivering enhanced heat resistance without compromising other essential properties of the material. Among the promising solutions are refractory alloys, which are known for their high melting points and resistance to deformation at elevated temperatures; however, their practical application is hindered by difficulties in fabrication and performance optimization.

To address these challenges, research has focused on developing film structures based on molybdenum oxide, which offers a versatile platform for tailoring the electrical and optical properties of modern electronics. The production of these films involves precise control over their composition and microstructure, enabling improved heat resistance and functional performance. Subsequent characterization using electrical and optical methods provides critical insights into their behavior under operational stress, facilitating the optimization of these materials for practical applications. This approach represents a significant step toward overcoming the limitations of conventional heat-resistant alloys and advancing the development of next-generation electronic components.

Keywords*: electron shell, valence, film structure, molybdenum oxide, molybdenum foil.*

Introduction

One of the significant challenges in modern microelectronics is the search for new material. Despite the rapid and significant development of silicon technology, the range of requirements and challenges facing modern electronics is so broad that new materials and technologies are required to meet them. From a practical perspective, transition metal oxides are promising materials. Owing to their unfilled electron shells, transition metals exhibit variable valence and form a wide range of compounds with oxygen.

The current development of modern technology (primarily in the rocket, space, and aviation industries) places several demands on alloys capable of operating at high temperatures, where traditional nickel-based alloys cannot be used.

Molybdenum plays a significant role in modern technologies. Of all the molybdenum consumed by the industry, up to 80% is used in the ferrous metallurgy industry for the production of heat-resistant, heat-resistant anti-corrosion, tool, high-speed, magnetic, and structural steels, as well as heat-resistant and heat-resistant cast irons. Molybdenum increases the strength of steels at low temperatures, promotes their retention at high temperatures, improves the heat resistance of steels and cast irons, and improves their hardenability. One part by weight of Mo increases the strength of steel equivalent to 2-2.5 parts by weight of wolfram.

Niobium, wolfram, and molybdenum oxides are known to possess electrochromic and photochromic properties. Nearly all transition metals exhibit the properties of electronic switches when combined with oxygen and undergo a metal-insulator phase transition [1].

The switching effect is associated with the formation or reversible electrical breakdown, which forms a conducting channel in the dielectric matrix of the base material. Despite intensive research, the study of switching phenomena continues, and the accumulation of experimental data contributes to the development of stable technical designs based on film structures with switching and memory properties. Furthermore, the study of switching phenomena is of interest for solving several problems related to the mechanism of the metal-semiconductor phase transition [2].

The relevance of this work lies in the search for new materials for practical applications, as well as the research and accumulation of experimental data in the field of phase transitions in solids.

The goal of this study was to obtain film structures based on molybdenum oxide, followed by an investigation of their physical properties using electrical and optical methods.

Properties of simple substances. The appearance of metallic Mo depends on the production method. Compact molybdenum (in the form of ingots, wire, sheets, or plates) is a fairly light but dull metal, whereas molybdenum obtained in a mirror-like form by decomposition, for example, of carbonyl, is shiny but gray. The molybdenum powder was dark gray. The density of Mo was 10,280 kg/m3. Its melting and boiling points are 2623 and 4639°C, respectively. Only one crystalline modification of the metal is known (at normal pressure), with a body-centered-cubic lattice. In its pure state, compact Mo is ductile and malleable, and can be stamped and rolled fairly easily. At high temperatures (but not in an oxidizing atmosphere), the strength of Mo exceeds that of most other metals. When contaminated with carbon, nitrogen, or sulfur, Mo, like Cr, becomes brittle and hard, significantly complicating its processing. Hydrogen is sparingly soluble in molybdenum and therefore cannot significantly affect its properties. Molybdenum is a good conductor of electricity, being only three times inferior to silver in this regard. Its electrical conductivity is greater than that of platinum, nickel, mercury, iron, and many other metals.

Under normal conditions, molybdenum is stable, even in humid air. Its reactivity depends on the degree of grinding, and fine powder still slowly oxidizes in humid air, producing the so-called molybdenum blue. Molybdenum begins to vigorously react with water vapor at 700°C and with oxygen at 500°C.

$Mo + 2H_2O = MoO_2 + 2H_2$

$2Mo + 3O_2 = 2MoO_3$.

Molybdenum burns in a fluorine atmosphere at 50–60 °C, and reactions with other halogens occur at higher temperatures.

$Mo + 3F_2 = MoF_6$

$2Mo + 5Cl_2 = 2MoCl_5$.

Dilute and concentrated mineral acids dissolve Mo when heated, but concentrated HNO_3 passivates it. At elevated temperatures, Mo reacts with sulfur, Se, As, nitrogen, carbon, and many other nonmetals.

The main industrial method for producing metallic Mo is the reaction of MoO_3 with hydrogen:

$MoO_3 + 3H_2 = Mo + 3H_2O$.

This process occurs in two or three stages. First, molybdenum anhydride is reduced to MoO_2 and then to a free metal. The first stage of reduction occurred at 550°C. If the second stage occurs below 900°C, the resulting metal contains a significant amount of oxygen, requiring a third stage of reduction at 1000–1100°C or higher. The metal obtained in this manner is suitable for processing using powder metallurgy methods.

For a long time, it was not possible to obtain molybdenum in a compact state, and a method for producing molybdenum wire was proposed only in 1907. The metal powder was mixed with an organic adhesive (sugar syrup) and forced through the die holes to form filaments. A direct electric current with a small potential difference was passed through the filaments in a hydrogen atmosphere. This generates intense heat, burning the organic material and sintering the metal particles to produce the wire.

Powder metallurgy techniques are now used to produce compact molybdenum, allowing ingots to be produced at temperatures significantly lower than the melting point of the metal. Powdered Mo was pressed in hydraulic presses in steel dies, heated in a hydrogen atmosphere at 1100–1300°C, and sintered at 2200°C in a hydrogen atmosphere in thick-walled Mo boats. Another common method is melting molybdenum in a vacuum using an electric arc generated between a rod of pressed molybdenum powder and a cooled copper electrode at a current of 7000 A and a small potential difference. Melting using a focused electron beam or argon plasma is sometimes used.

Molybdenum(II) oxide, $MoO_{0.93\text{-}0.97}$. When potassium vapor reacts with molybdenum oxygen compounds, a series of products containing $K_{1.5}MoO_3$ and $K_{0.6}MoO_2$ are formed. When exposed to water or alcohol, these products are converted to soluble molybdate, oxygen, and a black, sparingly soluble precipitate with strong reducing properties and a composition that is intermediate between $MoO_{0.93}$ and $MoO_{0.97}$.

Molybdenum(III) oxide, Mo_2O_3. A matte black powder. Density is 7.07 g/cm^3. It is slightly soluble in water. It is obtained by the dehydration of molybdenum(III) hydroxide and the reduction of molybdenum trioxide with liquid potassium or hydrogen.

Molybdenum(IV) oxide, MoO_2. It is a gray amorphous powder or violet-brown paramagnetic monoclinic crystal. Density is 6.47 g/cm^3. Stable in air, it slowly sublimes in a vacuum at 1100°C. It exhibits semiconducting properties. It is slightly soluble in water, acids, and alkali. It dissolves in oxidizing acid solutions. It is obtained by oxidizing metallic Mo with a mixture of water and hydrogen vapor at 700-800°C, gently heating the powdered metallic Mo in air, and reducing molybdenum trioxide with hydrogen, zinc, and Cd upon heating.

Molybdenum(V) oxide, Mo2O5. It is obtained in the form of a dark purple powder by the dehydration of molybdenum hydroxide in a stream of gaseous CO_2 (or nitrogen), as well as by the decomposition of compounds $Mo_2O(SO_4)_2$ and $Mo_2O(C_2O_4)_2$ in a stream of nitrogen.

Molybdenum(VI) oxide (MoO3). Weakly paramagnetic, birefringent, white, shiny, snow-like (yellowing when heated), and orthorhombic crystals with a layered structure. mp = 795°C, bp = 1255°C, density = 4.69 g/cm^3. It is soluble in water, excess alkali solutions, and alkali metal carbonates. It is obtained by calcining Mo in air at 570°C.

In addition, oxides with compositions intermediate between MoO_3 and MoO_2 have been obtained: Mo_8O_{23}, Mo_9O_{26}, Mo_4O_{11}, and $Mo_{17}O_{47}$. The bonding in the oxides is primarily ionic and partially covalent. MoO_2 is more refractory and thermodynamically stable than MoO_3.

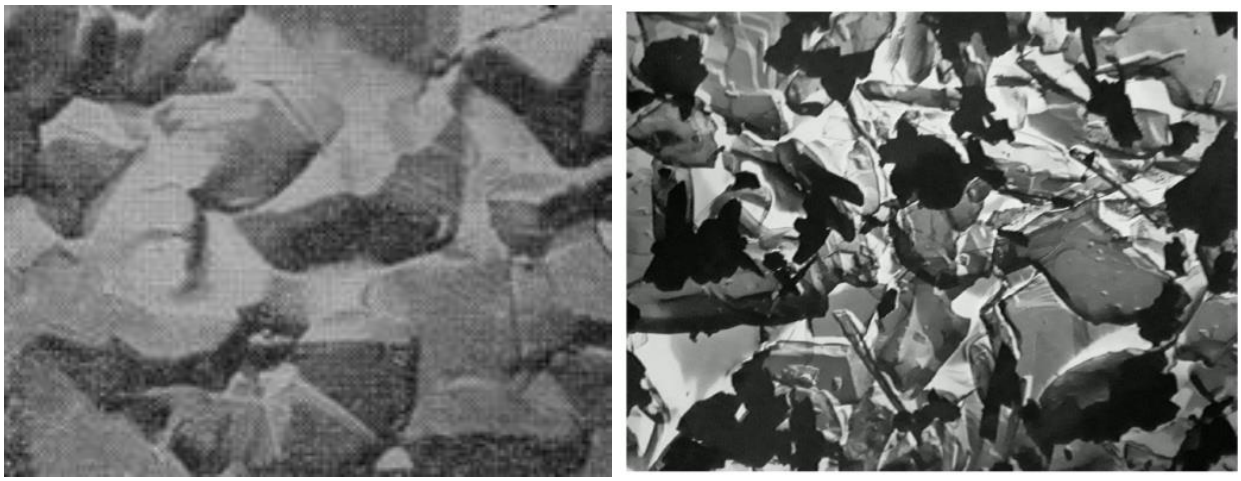
As molybdenum is a metal, its oxides should exhibit basic properties. However, the oxides MoO_3 and MoO_2 are acidic rather than basic. They form a series of compounds with general formulas of H_2MoO_4 and H_2MoO_3. The oxide Mo_2O_3 exhibits basic properties.

In terms of chemical properties, the oxide exhibits more basic properties, and the greater the electronegativity difference between the element and oxygen. The Pauling electronegativity of Mo is 1.8, whereas that of oxygen is 3.5. As can be seen, the electronegativity difference between the elements is 3.5 – 1.8 = 1.7.

The basic properties of molybdenum oxides can be confirmed by their interactions with acidic and alkaline solutions.

MoO_3 Films. Thin MoO_3 films have attracted considerable attention owing to their interesting structural, chemical, electrical, and optical properties [3-5]. These layers have wide applications in batteries, electrochromic devices, solar cells, gas sensors, and optoelectronic devices. Owing to its wide bandgap (Eg), MoO_3 can only absorb the short-wavelength portion of the solar spectrum, which limits its photovoltaic and photoelectrochemical applications. Along with these oxides, molybdenum oxide (MoO3) also has a wide band gap from 2.8 to 3.2 eV.

In works [6, 7], molybdenum foil Mo was pre-oxidized in nitric acid HNO_3, then the oxide was removed in hydrofluoric acid HF, followed by rinsing in distilled water. In addition, the substrate was subjected to gas etching for 30 min in the chamber of the gas deposition reactor at a temperature higher than the deposition temperature in a hydrogen flow, H_2. The temperature of the source T_i and the substrate T_p varied in the range of 850 ÷ 900 ^{0}C, and the cooling rate was in the range of the cooling rate of 10^{-5} deg/min. Structural analysis of the "substrate Mo-MoO_3" boundary was carried out using X-ray diffraction with an MIM-7 microscope and a Cameka microanalyzer. An amorphous structure with a columnar shape was clearly visible in the MoO_3 films (Fig. 1).



(a) ***(b)***

Fig. 1. Mo foil film without surface treatment (magnification 1500) (a); MoO_3 film on the surface of Mo substrate (magnification 3500) (b).

The XRD patterns of MoO_3 (000) thin films showed that Mo^{+5} in the film accounted for only 3% of the total Mo_{3d} peak, indicating that the film was predominantly in the Mo^{+6} oxidation state, that is, stoichiometric. AFM analysis of pure MoO_3 films showed the highest transmittance in the visible region of the spectrum, where the absorption edge shifted toward higher wavelengths of the solar spectrum [7]. The absorption coefficient (α) of the obtained films was determined from the transmittance spectrum values (T) using the ratio

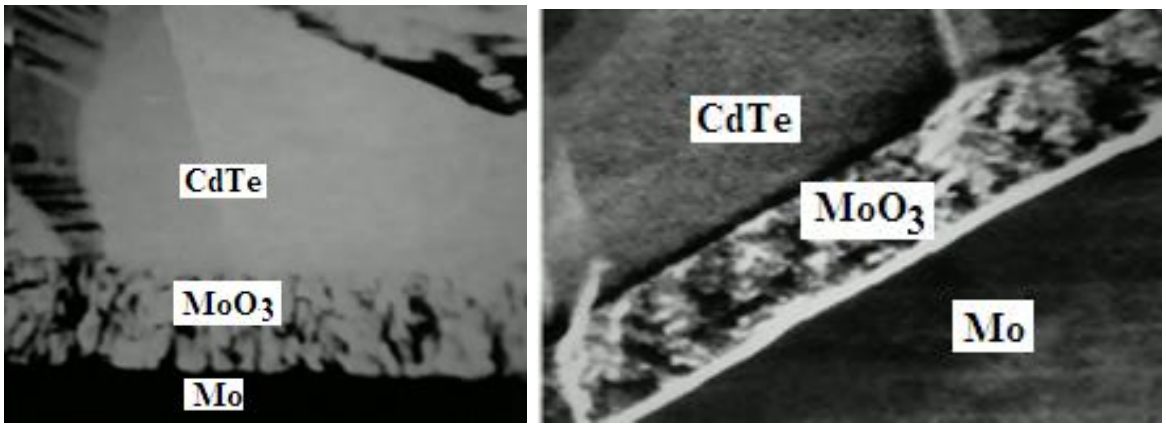
$$T = exp\ -\alpha\ d \qquad (1)$$

where d is the film thickness, and

CdTe is a highly absorbing material with a high optical absorption coefficient (~10^5 cm^{-1}) in the visible region of the solar spectrum. These results indicate the potential of CdTe-doped MoO_3 films for efficient light absorption in solar cells.

In our case, CdTe films were formed on a Mo substrate in a single process cycle [8,9]. The substrate is a Mo-molybdenum foil with a thickness of ~300 μm, which is pre-oxidized in HNO3, then the oxide is removed in HF, followed by rinsing with distilled water. Before deposition, the Mo substrate was placed in the deposition zone for 1 h and subjected to gas etching in an atmosphere of hydrogen carrier gas. The source and substrate temperatures varied in the ranges of 750–950 °C and 500–700 °C, respectively.

To study the structure of the Mo – CdTe interface, the CdTe film was separated from the Mo substrate, and the surfaces of the Mo and MoO_3 films adjacent to the CdTe and the substrate adjacent to the film were studied separately (Fig. 2 a, b), as well as the X-ray diffraction pattern of the structure.



a) ***b)***

Fig. 2. Micrograph of the interface between Mo and CdTe (a) magnification 980 M: 1 cm–10.2 μk) and the interface between Mo and CdTe (b) magnification 1750 (M: 1 cm–3.7 μk).

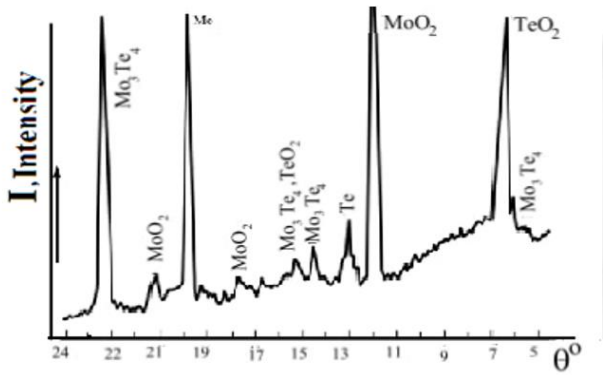


Fig. 3. Actual structure of Mo–CdTe interface.

Based on the obtained micrograph and X-ray phase analysis results, it was confirmed that the original high-purity Mo substrate did not contain any oxides on its surface. The oxide MoO_3 is formed during the synthesis process, in contact with the heated Mo substrate, as a result of a chemical interaction with the residual O_2 in the system.

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METHODS FOR REDUCING DISPERSION PHENOMENA IN OPTICAL FIBERS

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https://doi.org/10.5281/zenodo.19722833

Abstract. *This article presents a comprehensive analysis of the dispersion phenomenon in optical fiber communication systems, its physical nature, and its impact on signal transmission performance. Dispersion leads to temporal broadening of optical pulses, resulting in signal distortion, intersymbol interference, and limitations on transmission speed and distance. The study examines the main types of dispersion, including chromatic dispersion (material and waveguide components), modal dispersion, and polarization mode dispersion.*

Special attention is given to the role of dispersion in modern high-speed optical communication systems and its impact on network efficiency. Various dispersion mitigation and compensation techniques are analyzed, such as dispersion compensating fibers (DCF), optical compensators, fiber Bragg gratings, soliton-based transmission, and digital signal processing (DSP) methods. The results demonstrate that effective dispersion management is essential for improving the reliability and capacity of optical communication networks.

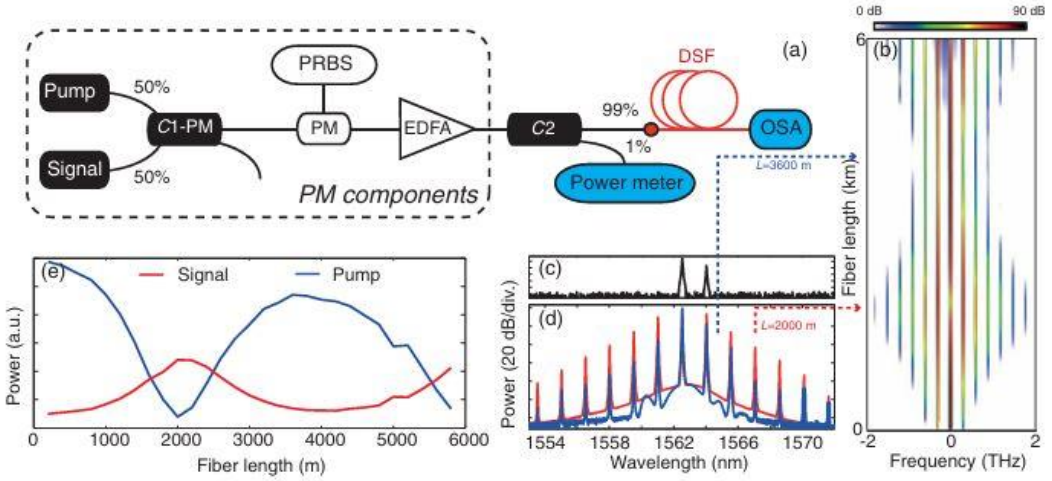
Keywords: *optical fiber communication, dispersion, chromatic dispersion, modal dispersion, polarization mode dispersion, DCF, DSP, solitons, optical networks.*

INTRODUCTION

As a result of the rapid development of modern information and communication technologies, the demand for high-speed and large-volume data transmission has been increasing significantly. In particular, the expansion of internet networks, the advancement of cloud technologies, multimedia services, and the deployment of 5G and next-generation mobile communication systems have further intensified the need for optical fiber communication systems. Optical fiber communication systems are considered superior to other transmission media due to their high bandwidth capacity, low signal loss, and resistance to electromagnetic interference.

At the same time, there are several physical factors that affect the efficient operation of optical fiber communication systems, among which dispersion is one of the most significant. Dispersion leads to the temporal spreading of signal pulses as a result of different wavelength components of the optical signal propagating at different velocities. This phenomenon causes signal distortion, overlap of adjacent pulses, and consequently reduces the accuracy of transmitted data.

Dispersion is particularly a critical issue in high-speed and long-distance optical communication systems. As the transmission speed increases, the duration of pulses becomes shorter, making them more sensitive to the effects of dispersion. As a result, signal distortion occurs more rapidly, leading to a decrease in the overall performance efficiency of the system. Therefore, an in-depth study of dispersion, identification of its types, and the development of effective mitigation methods are among the most important challenges in modern optical communication systems.



In optical fibers, several main types of dispersion exist, among which chromatic dispersion (including material and waveguide dispersion), modal dispersion, and polarization mode dispersion play a significant role. Each type of dispersion affects signal transmission in its own way, and different technological approaches are required to mitigate them effectively In the experimental setup shown in Figure 1(a),

In this experiment, we use two monochromatic tunable diode lasers generating the pump and signal waves, as shown in the upper-left corner of Figure 1. The two optical fields are combined through a polarization-maintaining 50:50 coupler. Each of them is phase-modulated with a 3 Gbit/s pseudo-random bit sequence in order to suppress the stimulated Brillouin scattering (SBS) effect.

Subsequently, the two waves are amplified in an erbium-doped fiber amplifier (EDFA) before being launched into the dispersion-shifted fiber (DSF). To achieve complete matching between the polarization states of the pump and signal waves prior to their injection into the DSF, adjustment is performed using polarization-maintaining components placed before the second coupler, C2. The DSF is similar to that described in Ref. [22]. The total power of the pump and signal launched into the fiber is 27.7 dBm, with a power difference of 11 dB between the pump and the signal.

Figure 1(a) shows the experimental setup. The notations are as follows: C1 and C2 – optical couplers; PRBS – pseudo-random bit sequence; PM – phase modulator; and OSA – optical spectrum analyzer. The experimental results include: (b) the evolution of the spectrum as a function of fiber length; spectra recorded at specific lengths (c) L=0L = 0L=0 m and (d) L=2000L = 2000L=2000 m (red curve) and L=3600L = 3600L=3600 m (blue curve); and (e) the evolution of pump and signal powers along the fiber length. All these experimental results were obtained with a second-order dispersion value of β2=−1.116×10−27 s2/m\beta_2 = -1.116 \times 10^{-27}\ \text{s}^2/\text{m}β2=−1.116×10−27 s2/m (i.e., 11.7 nm above the zero-dispersion wavelength, ZDW).

In other words, PP=530P_P = 530PP=530 mW and PS=44.7P_S = 44.7PS=44.7 mW. In order to achieve the maximum modulation instability (MI) gain, the signal wavelength is selected at the peak of the MI gain band. This corresponds to a value of α=0.25\alpha = 0.25α=0.25, which is the dimensionless parameter used in the standard Akhmediev Breather (AB) theory [16]. This wavelength is experimentally determined from MI spectra recorded without launching the signal into the fiber, i.e., under noisy initial conditions.

Special care is taken to maintain constant power levels of both waves during wavelength sweeping (with maximum fluctuations of 0.3 dB). Before investigating the role of third-order dispersion (TOD) in the Fermi–Pasta–Ulam (FPU) process, we ensured that our experimental setup allows the observation of a “standard” FPU recurrence in optical fibers, as reported in Refs. [4,5].

To do so, we first identify a configuration in which the effect of TOD is negligible. The pump wavelength is fixed sufficiently far from the fiber’s zero-dispersion wavelength (ZDW) so that the dispersion can be assumed constant over the entire spectrum. Figure 1(b) illustrates the evolution of the spectrum along the fiber length. An immediate observation is that the spectrum is nearly symmetric on both sides of the pump wavelength, as expected from the theory based on the nonlinear Schrödinger equation (NLSE) [9]. This confirms that a configuration with negligible TOD influence has been achieved.

A second important observation is that the MI process naturally evolves into an FPU recurrence as the fiber length increases. The energy, initially confined to the pump and signal waves [see the input spectrum in Fig. 1(c)], is progressively transferred to harmonics of the signal on both sides of the pump [Figs. 1(b) and 1(d)]. For a clearer understanding, Fig. 1(d) shows the evolution of the signal and pump powers as a function of fiber length.

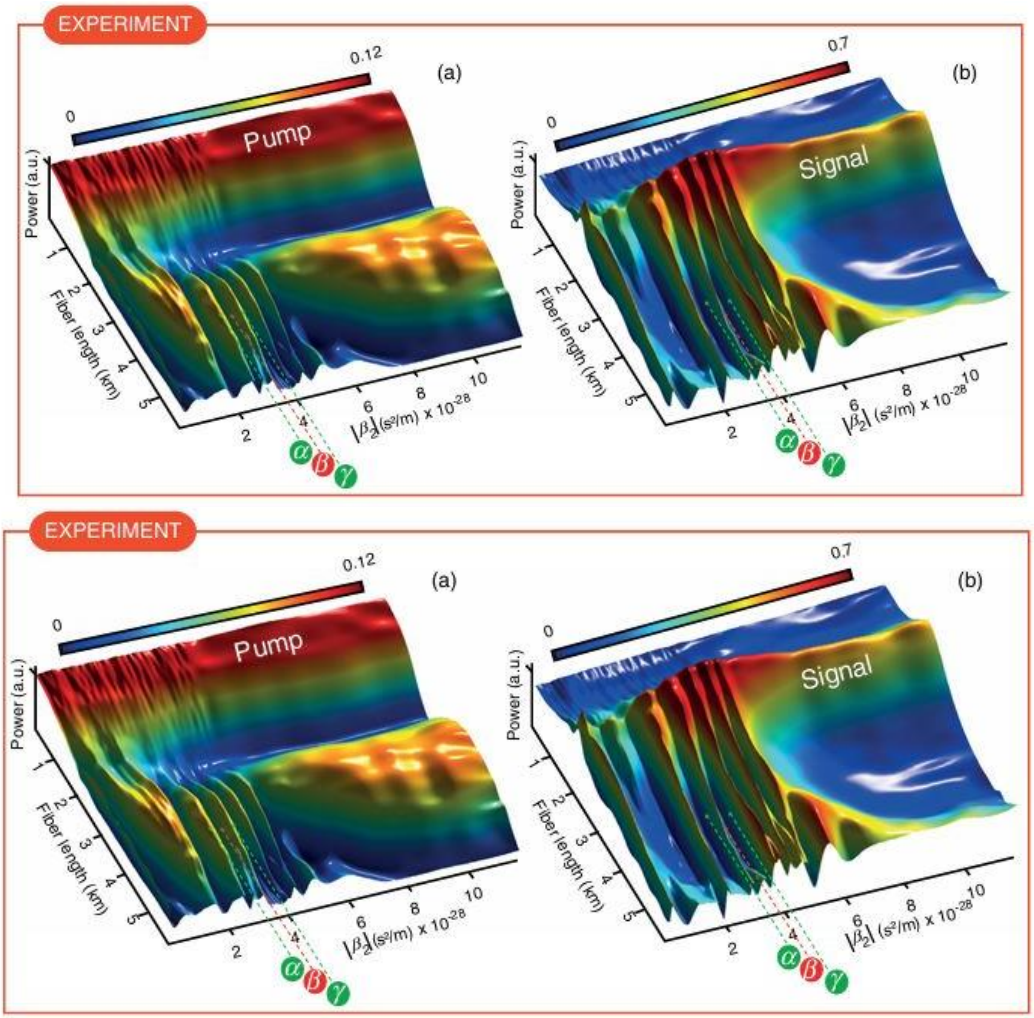
The maximum energy transfer reaches 92% at L=2000L = 2000L=2000 m, with only 8% of the energy remaining in the pump. At this point, the signal power is maximal and the spectrum is the broadest, with more than six harmonics generated on each side of the spectrum (see the red curve in Fig. 1(d)). After this point, the energy transfer reverses, and the process begins to return energy back toward the pump.

To investigate the influence of TOD, the pump wavelength is then shifted toward the fiber’s ZDW. As a result, the MI spectra, whose bandwidth is inversely proportional to the second-order dispersion, broaden significantly, and the dispersion can no longer be considered constant across the entire spectral range. Therefore, it becomes necessary to include the TOD term in the analysis, as is commonly done in studies of modulation instability in low-dispersion optical fibers [22,24,25].

From this point along the fiber length, the energy begins to flow back from the harmonics to the pump. It reaches approximately 79% of the initial pump power at L=3600L = 3600L=3600 m (see Fig. 1(e) and the blue curve in Fig. 1(d)). This high value indicates that the FPU process is highly efficient. Indeed, considering only linear losses, the pump power after propagation over 3600 m of fiber would be expected to be about 84% of its initial value.

Thus, one full cycle of the process is observed, where energy flows from the pump to the sidebands and then back again, forming a recurrence cycle. We observe approximately one and a half periods of recurrence, consistent with the original work of These experimental results are well supported by realistic numerical simulations performed through the integration of the generalized nonlinear Schrödinger equation.

Here, β2,β3,β4\beta_2, \beta_3, \beta_4β2,β3,β4 represent the second-, third and fourth-order dispersion terms, respectively; γ\gammaγ is the nonlinear coefficient of the fiber; and hR(t)h_R(t)hR(t) denotes the Raman response obtained from experimental measurements. The numerical integration is performed using an adaptive split-step Fourier method [35], with a precision of 10−710^{-7}10−7.



We use parameters that are close to the experimental conditions:

b2ðlPÞ¼−100×10−29 dan −1×10−29 s2=m (200 qadam), b3ðlPÞ¼1,2×10−40 s3=m, b4ðlPÞ¼−2,5 ×10−55 s4=m, g ¼2,4=Vt=km, fiber length L ¼ 6000 m, chiziqli zaiflashuv a ¼ 0,2 dB=km, PP¼530mVt va PS ¼ 44,7 mVt.

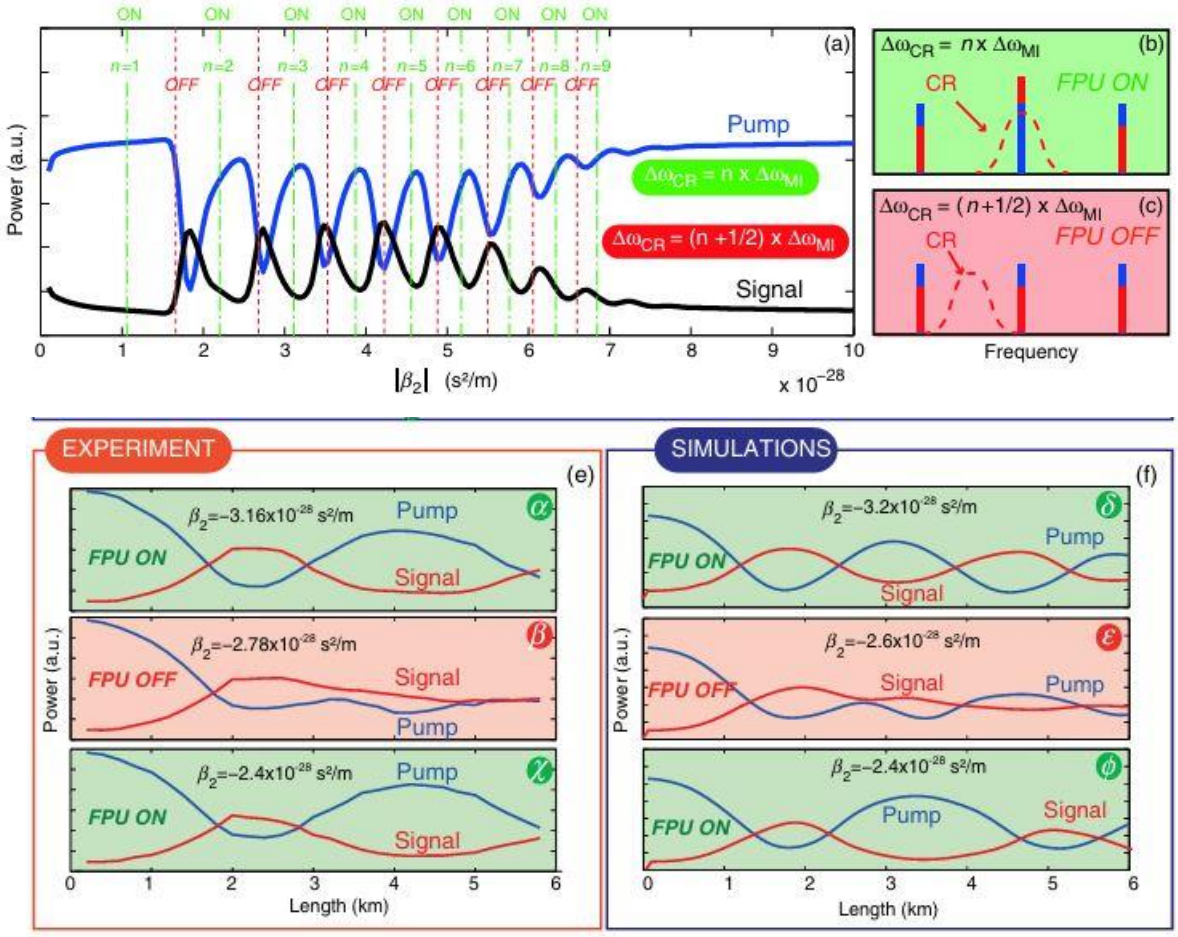
Although no adjustable fitting parameters were used, excellent agreement with the experimental results is achieved. In addition, the onset of the second recurrence period occurs at L=3000 mL = 3000 \ \text{m}L=3000 m in simulations, compared to L=4000 mL = 4000 \ \text{m}L=4000 m in the experiment. This slight discrepancy can be attributed to uncertainties in pump power measurements, longitudinal fluctuations of dispersion, and/or polarization mode dispersion in the real fiber.

$$\frac{\partial E(z,\tau)}{\partial z} = -i\frac{\beta_2}{2}\frac{\partial^2 E(z,\tau)}{\partial \tau^2} + \frac{\beta_3}{6}\frac{\partial^3 E(z,\tau)}{\partial \tau^3} + i\frac{\beta_4}{24}\frac{\partial^4 E(z,\tau)}{\partial \tau^4}$$
$$+ i\gamma|E|^2 E(z,\tau) + i\gamma\int h_R(t)|E(z,\tau-\tau')|^2 d\tau' E(z,\tau),$$

In a previous theoretical study by one of us (see Ref. [26]), it was predicted that the FPU recurrence process would vanish under the influence of dispersion slope and reappear in the very low-dispersion regime. In the present work, we find that the dynamics are significantly more

complex, as there exists a range of |β2|\beta_2||β2| values where the behavior changes qualitatively.

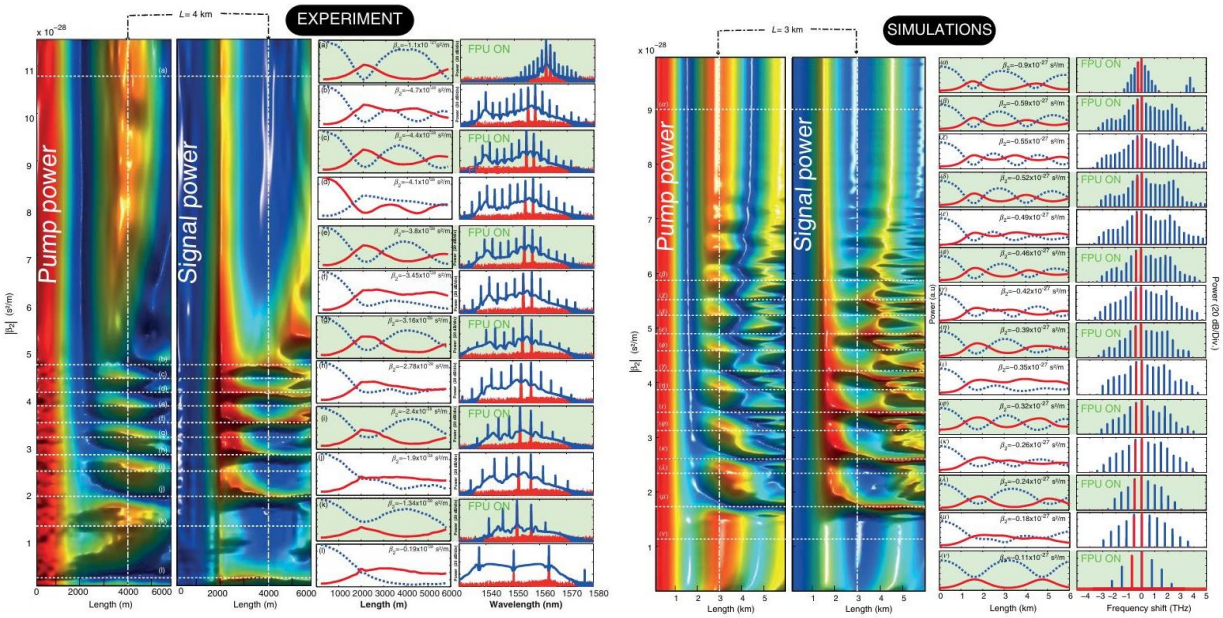
Figure 3: (a) Evolution of the pump power (solid blue curve) and the first harmonic power (solid black curve) as a function of second-order dispersion values. The green vertical lines indicate the |β2|\beta_2||β2| values where Cherenkov radiation (CR) is precisely phase-matched with the modulation instability (MI) harmonics, while the red dotted lines indicate the |β2|\beta_2||β2| values where CR is located between two harmonics. The labels “ON” at the top indicate the regions where FPU recurrence is maximized.



(b) Consequence of perfect phase matching between MI harmonics and CR. (c) Phase mismatch case. In (b) and (c), solid curves represent CR spectra. Spectral components shown in blue correspond to the field before CR generation, while red curves represent components after CR generation is irreversible. Conversely, when Cherenkov radiation is generated between two consecutive MI harmonics, a large part of their energy is lost by several reversible four-wave mixing processes [see Here the losses are reversible and this leads to the suppression of the FPU repetition due to the appearance of Cherenkov radiation. This procedure leads to multiple disappearances. Numerical data. Left two columns: incorrect color scheme of the pump and signal powers with respect to the fiber length and dispersion. Third column: evolution of the signal power (solid red lines) and the dotted blue lines of the pump power with respect to the fiber length for eigenvalues of the dispersion. Right column: Corresponding spectrum L¼3000m (blue lines) and L¼0 (red lines). The two right light pink panels show the FPU repetition on states, while the white panels show the FPU repetition off states.

CONCLUSION

In conclusion, the dispersion phenomenon in optical fiber communication systems is one of the important physical factors that significantly affects the quality of signal transmission. As a result of dispersion, optical pulses expand in time, which leads to distortion of the signal shape, the appearance of intersymbol interference, and limitations in transmission speed and distance. Especially in high-speed and long-distance transmission systems, the negative effect of dispersion is more pronounced.



The experiment conducted below shows that the main types of dispersion - chromatic dispersion due to materials and waveguide components, modal dispersion, and polarization-modal dispersion - each have different effects on the optical signal, and appropriate technological approaches must be used to reduce them. In particular, although modal dispersion has almost disappeared in single-mode fibers, the problem of chromatic and polarization dispersion remains relevant.

Various advanced methods are widely used to reduce and control dispersion in modern optical communication systems. In particular, dispersion-compensating fibers, optical compensators, fiber Bragg gratings, soliton transmission technologies, and digital signal processing (DSP) methods provide high efficiency. These technologies allow reducing signal distortion, improving transmission quality, and increasing the overall stability of the system. As a result of the analysis, it can be noted that effective dispersion control is of great importance in increasing the throughput of optical communication systems, extending transmission distances, and ensuring high-speed data exchange. In the future, the development of new technologies for reducing dispersion in optical communication systems, the widespread use of artificial intelligence and digital modeling methods will serve the further development of this area. Therefore, in-depth study of the dispersion phenomenon in optical fiber systems and the introduction of effective methods for its reduction will remain one of the important directions for improving modern telecommunications infrastructure.

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INTERPRETATION OF ELASTIC AND INELASTIC MOLECULAR COLLISIONS IN MOLECULAR PHYSICS WITHIN CHEMICAL SCIENCE

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https://doi.org/10.5281/zenodo.20033864

Abstract*. This study presents a theoretical analysis of elastic and inelastic molecular collisions within the framework of molecular physics and their interpretation in chemical science. Based on the principles of the kinetic theory of gases, the research examines molecular motion, intermolecular interactions, and collision processes. Elastic collisions are analyzed in terms of the conservation of momentum and kinetic energy, while inelastic collisions are considered in relation to energy transformation into internal forms such as heat and excitation energy. Special attention is given to the role of inelastic collisions in chemical reactions, including activation energy and collision theory. The findings highlight the strong interconnection between molecular physics and chemistry, demonstrating that molecular collision processes form the basis for understanding both physical properties and chemical transformations.*

Keywords*: molecular physics, elastic collision, inelastic collision, kinetic theory of gases, activation energy, chemical kinetics, energy exchange, diffusion, molecular motion.*

Introduction

In recent decades, the rapid development of modern physics has led to the emergence of new scientific fields, including plasma physics, particle physics, semiconductor physics, biophysics, and solid-state physics. These advancements have not only expanded theoretical knowledge but have also contributed to technological progress, enabling the development of advanced research tools such as particle accelerators and high-precision experimental equipment. The evolution of physics is closely connected with industrial and technological development, as scientific discoveries are continuously applied in engineering and production processes [1].

From a historical perspective, the development of physics has always been closely linked to the advancement of other natural sciences, particularly chemistry. Many fundamental concepts used in modern science originate from early attempts by ancient civilizations to understand the structure of matter and natural phenomena. Today, physics is recognized as a fundamental science because it provides the underlying principles that govern all natural processes. Other sciences, such as chemistry and biology, investigate specific systems that operate according to physical laws [2].

Chemistry, for instance, focuses on the composition, structure, and transformation of substances. However, these transformations are fundamentally governed by physical interactions at the molecular level. The properties of substances, including their chemical behavior, are determined by the physical characteristics of atoms and molecules, which are studied within molecular physics, thermodynamics, and quantum mechanics. Therefore, the study of molecular interactions—particularly molecular collisions—is essential for understanding both physical and chemical processes [2].

Molecular physics investigates the structure of matter and the laws governing molecular motion. According to the kinetic theory of gases, matter consists of molecules that are in constant random motion and continuously collide with one another. These collisions play a crucial role in determining macroscopic properties such as pressure, temperature, and diffusion. Molecular collisions can be broadly classified into elastic and inelastic types, each of which has distinct characteristics and implications [3].

Elastic collisions are defined as interactions in which the total kinetic energy and momentum of the system are conserved. These collisions are fundamental for explaining physical phenomena such as gas pressure, diffusion, and thermal motion. In contrast, inelastic collisions involve the transformation of kinetic energy into other forms, such as internal energy, heat, or deformation, and are particularly important in chemistry as they provide the mechanism through which chemical reactions occur [4].

The purpose of this study is to analyze the nature of elastic and inelastic molecular collisions, to explore their role in molecular physics, and to examine their significance in chemical processes.

Literature Review

The interpretation of elastic and inelastic molecular collisions has been extensively examined in both molecular physics and chemical science, where it is considered a complex and multidimensional concept grounded in fundamental theoretical principles. Early studies within the framework of the kinetic theory of gases established that matter consists of molecules in constant random motion, whose interactions and collisions determine macroscopic properties such as pressure, temperature, and diffusion [5]. In classical physics, these processes are explained through the laws of conservation of momentum and energy, with elastic collisions playing a central role in the development of the ideal gas model, while subsequent research expanded the understanding of inelastic collisions, demonstrating that part of the kinetic energy is transformed into internal energy, heat, or other forms. In chemistry, this problem has been further developed within the field of chemical kinetics, where collision theory provides a scientific explanation for reaction mechanisms by defining the necessary conditions for effective molecular collisions, including sufficient activation energy and proper spatial orientation. The theoretical contributions of Svante Arrhenius significantly advanced this field by introducing the concept of activation energy as a key factor governing reaction rates, while later studies in physical chemistry have explored intermolecular interactions, energy exchange processes, and the factors influencing reaction kinetics in greater depth [6]. In modern research, advances in molecular dynamics simulations and quantum chemical methods have enabled more detailed investigations of collision processes at the microscopic level, allowing for the analysis of particle trajectories, energy redistribution, and reaction pathways. At the same time, the rapid development of natural sciences has emphasized the importance of integrating molecular physics and chemistry to better understand molecular motion, interactions, and energy transformations, particularly in the context of developing new materials and advanced technologies. Modern technological progress increasingly relies on synthetic materials with predetermined properties, the creation of which depends on precise control of molecular interactions using advanced physical methods such as electron and ion beams, high-pressure and high-temperature conditions, and electromagnetic fields [7]. Furthermore, elastic and inelastic collisions remain central to explaining both physical properties and chemical processes, as elastic collisions contribute primarily to the understanding of thermodynamic behavior, while inelastic collisions are directly responsible for chemical reactions through energy

exchange and bond formation or breaking. These processes are critically important in various applied fields, including industrial chemistry, pharmaceuticals, nanotechnology, and environmental science, where understanding reaction kinetics and molecular interactions is essential for optimizing processes and addressing global challenges [8]. Overall, the literature demonstrates that despite extensive research, the integrated analysis of elastic and inelastic collisions at the intersection of molecular physics and chemistry remains a highly relevant and evolving area of scientific inquiry.

Methods

This study utilizes a qualitative theoretical research design grounded in the systematic analysis and synthesis of scientific literature in molecular physics and chemical science. The methodological framework is interdisciplinary, integrating key principles from the kinetic theory of gases, classical mechanics, and chemical kinetics to develop a coherent understanding of molecular collision processes. This approach facilitates the investigation of molecular interactions from both physical and chemical perspectives, ensuring a comprehensive interpretation of elastic and inelastic collisions within a unified scientific context. The core of the methodology is a conceptual-analytical approach, employed to define and interpret the fundamental characteristics of molecular collisions. Particular attention is given to the governing physical laws, including the conservation of momentum and kinetic energy, as well as the mechanisms of energy transformation during interactions. Additionally, a comparative analytical method is applied to distinguish elastic and inelastic collisions across key parameters such as energy conservation, momentum transfer, and energy exchange. This comparison allows for a structured evaluation of how different types of collisions influence both macroscopic properties (e.g., pressure and temperature) and microscopic processes (e.g., reaction mechanisms and bond formation). Furthermore, the study incorporates elements of structural analysis to elucidate the relationships between core concepts such as molecular motion, intermolecular interactions, activation energy, and collision theory. To strengthen the theoretical framework, insights from modern approaches, including molecular dynamics and quantum chemical methods, are employed to support and contextualize classical models. This combination of traditional and contemporary perspectives ensures a consistent and scientifically grounded analysis, providing a solid foundation for understanding the role of molecular collisions in both physical phenomena and chemical processes.

Results

The analysis substantiates that molecular collisions are essential processes that dictate both the physical properties of matter and the mechanisms underlying chemical reactions. According to the kinetic theory of gases, molecules are perpetually in motion and incessantly collide with one another. These collisions result in alterations in velocity, direction, and energy distribution, which subsequently affect macroscopic properties such as pressure and temperature. Elastic collisions are characterized by the conservation of both momentum and kinetic energy. During these interactions, molecules may experience temporary deformation, yet their internal structure remains unaltered, and no energy is dissipated. Consequently, elastic collisions predominantly contribute to physical phenomena such as gas pressure, diffusion, and thermal motion. Conversely, inelastic collisions involve the conversion of kinetic energy into other forms, including internal energy, heat, or excitation energy. These collisions may modify the internal state of molecules, encompassing changes in vibrational and rotational energy levels. In numerous instances, inelastic

collisions can lead to the breaking or formation of chemical bonds, thereby initiating chemical reactions.

A systematic comparison of elastic and inelastic collisions is presented below:

Table 1. Comparison of Elastic and Inelastic Molecular Collisions

Property	**Elastic Collision**	**Inelastic Collision**
Energy conservation	Yes	No
Momentum conservation	Yes	Yes
Energy exchange	No	Yes
Effect on chemical reactions	Low	Very high

The data presented in Table 1 clearly illustrate the fundamental distinctions between the two types of molecular collisions. While elastic collisions conserve the total kinetic energy of the system and primarily affect physical properties, inelastic collisions involve energy transformation and play a crucial role in chemical processes. Furthermore, the results underscore that in chemical kinetics, collision theory is employed to elucidate reaction rates. According to this theory, the rate of a chemical reaction is contingent upon three principal factors: the frequency of molecular collisions, the energy of these collisions, and the spatial orientation of the interacting particles. Only those inelastic collisions that satisfy the conditions of sufficient activation energy and proper orientation are deemed effective and result in chemical reactions.

Discussion

The results of this research highlight the deep connection between molecular physics and chemistry. Molecular collisions serve as a bridge between these fields, linking microscopic interactions to macroscopic properties and chemical processes. Understanding the distinction between elastic and inelastic collisions is vital for grasping how matter behaves. Elastic collisions explain how energy is distributed within a system without changing its internal structure, while inelastic collisions provide insights into energy transformation and chemical reactivity. The role of inelastic collisions in chemical reactions is particularly significant. Arrhenius's concept of activation energy emphasizes that only collisions with enough energy can lead to chemical changes. This explains why reaction rates depend on factors like temperature, pressure, and concentration. For example, increasing temperature raises molecular kinetic energy, thus increasing the likelihood of effective collisions. Additionally, the study shows that modern scientific techniques, such as molecular dynamics simulations and quantum chemical methods, offer deeper insights into collision processes. These methods allow researchers to examine molecular interactions in detail, advancing fields like materials science, nanotechnology, and pharmaceuticals. The practical implications of understanding molecular collisions are substantial. In industrial chemistry, controlling reaction rates and optimizing production processes require precise knowledge of collision dynamics. Similarly, in environmental science, understanding molecular interactions in the atmosphere is crucial for addressing issues like pollution and climate change. In conclusion, the findings confirm that studying molecular collisions is not only theoretically important but also has significant practical applications across various scientific and technological fields.

Conclusion

In conclusion, elastic and inelastic molecular collisions form a fundamental basis for elucidating the behavior of matter in molecular physics and for comprehending reaction mechanisms in chemistry. Elastic collisions are characterized by the conservation of total kinetic

energy and momentum, resulting solely in alterations in the velocity and direction of molecules without impacting their internal structure or chemical bonds. Consequently, such collisions are primarily associated with physical phenomena, including gas pressure, diffusion, and thermal motion, and they do not lead to chemical transformations. Conversely, inelastic collisions involve the redistribution of kinetic energy into internal forms such as vibrational or rotational energy. These processes are critically important in chemistry, as they establish the necessary conditions for chemical reactions. When colliding molecules possess sufficient activation energy and the appropriate spatial orientation, chemical bonds may break or form, leading to the production of new substances. This principle underlies the concept of effective collision theory, which posits that only specific inelastic collisions—those meeting defined energetic and geometric conditions—result in chemical reactions. Overall, the distinction between elastic and inelastic collisions provides a deeper understanding of molecular-level processes and allows for a more accurate explanation of reaction rates and physical properties of substances. The study confirms that reaction kinetics depend not only on the frequency of collisions but also on the energy and orientation of interacting molecules. Consequently, factors such as temperature, pressure, concentration, and the presence of catalysts play a decisive role in influencing reaction efficiency. These insights establish collision theory as a key scientific foundation for controlling chemical processes, optimizing industrial technologies, and advancing developments in materials science, applied chemistry, and related fields.

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FEATURES OF SEMICONDUCTOR DEVICES UNDER ACTIVE DEVELOPMENT IN OPTOELECTRONICS

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Abstract. *In this scientific text, the theoretical foundations of optoelectronics and the operating principles of semiconductor devices are analyzed. It examines the interaction between light and charge carriers, electron–hole processes, and the role of quantum mechanical phenomena in optoelectronic devices. Furthermore, light-emitting and light-receiving devices, energy conversion systems, and the application of modern materials are scientifically generalized. In this work, the main characteristics of optoelectronic devices, such as efficiency, speed, and energy efficiency, are systematically analyzed, and their fields of practical application are also considered. In addition, the prospects of new directions based on nanomaterials and innovative materials are evaluated. This study highlights the modern development trends in the field of optoelectronics and serves as a theoretical foundation for future scientific and technological research.*

Keywords: *optoelectronics, semiconductor devices, p–n junction, electron–hole pair, recombination process, photoelectric effect, electroluminescence, band gap, nanostructures, quantum dots, light-emitting diode, laser diode, photodiode, solar cell, optical fiber communication.*

INTRODUCTION

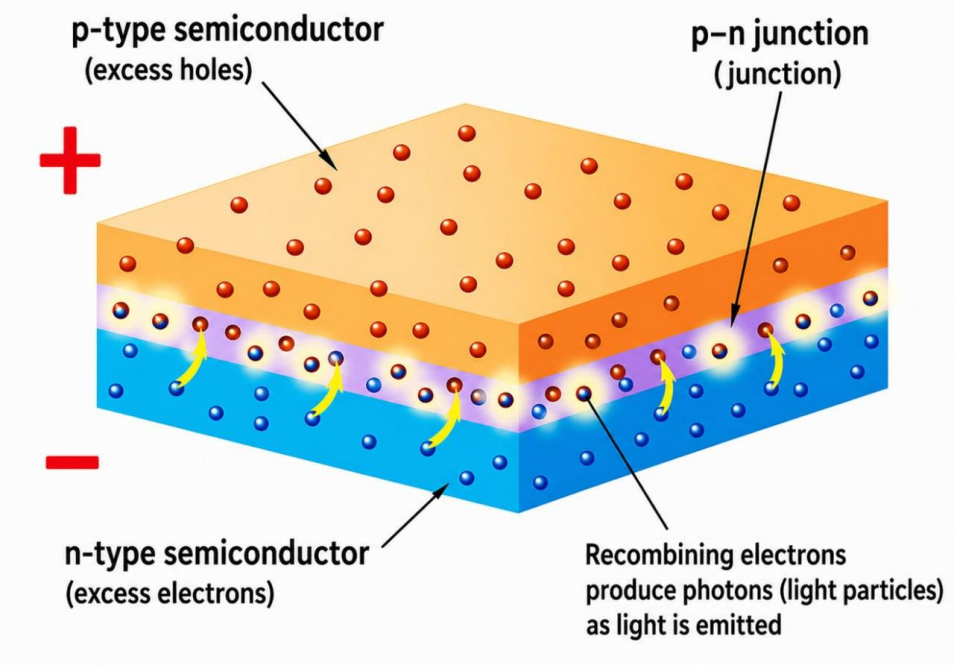
Optoelectronics is an important scientific and technological field that studies devices based on the interaction between light (photons) and charge carriers (electrons and holes). This field is formed at the intersection of physics, electronics, and materials science, and has become one of the main drivers of modern technologies.

The operating principle of optoelectronic devices is based on quantum processes occurring within semiconductor materials. The formation of electron–hole pairs, the recombination process, and the emission or absorption of photons play a crucial role.

For example, when an external voltage is applied, electrons and holes recombine, and energy is released in the form of photons—this phenomenon is called electroluminescence and forms the basis of the operation of LEDs and laser diodes. Conversely, the generation of charge carriers under the influence of light is explained by the photoelectric effect and is applied in the operation of photodiodes and solar cells.

LED (Light-Emitting Diode) is a semiconductor-based radiation source that emits light directly when an electric current passes through it. Its basic structure consists of a p–n junction, where p-type material (rich in holes) and n-type material (rich in free electrons) are brought into contact.

When the device is supplied with a forward bias voltage, charge carriers accumulate in the active region, and the energy emission process begins.



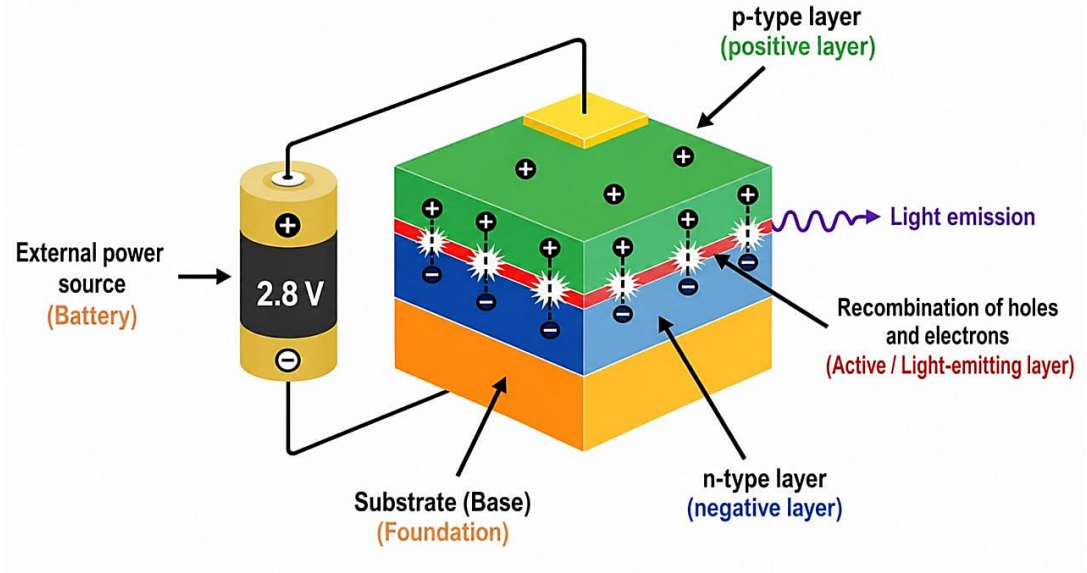
Ris 1. Principle of p–n Junction Formation During Photon (Light) Transmission

An important characteristic of an LED is that the color of the emitted light depends on the energy structure of the semiconductor material used. Here, the band gap energy plays the main role. For example:

- small band gap → red or infrared light
- medium band gap → green or yellow light
- large band gap → blue and ultraviolet light

For this reason, various materials are used in LED fabrication, such as gallium arsenide (GaAs), gallium phosphide (GaP), gallium nitride (GaN), indium gallium nitride (InGaN), and others.

In particular, the development of blue LEDs has led to a major breakthrough in lighting technology, since white LEDs are produced based on them (through phosphor coating).



Ris 2. Structure and Operating Principle of a Light Emitting Diode (LED).

Another important aspect of LEDs is their high efficiency. Unlike conventional lamps, LEDs convert a large portion of energy into light rather than heat. At the same time, they operate at low voltage, switch on and off rapidly, and are mechanically robust.

From a structural point of view, an LED consists of the following main components:

- semiconductor chip (the part where the active layer is located)
- electrodes (for current injection)
- reflector or optical encapsulation (for directing light)
- heat dissipation element (heat sink) — especially in high-power LEDs

Thermal management is very important for LED efficiency. If heat is not adequately dissipated, the light output of the device decreases and its lifetime is shortened. Therefore, modern LED modules use aluminum-based heat sinks and special thermal conductive materials.

MATERIALS AND METHODS

This study was conducted through theoretical and analytical methods. Scientific literature on optoelectronics, semiconductor physics, p–n junctions, light-emitting devices, photodiodes, solar cells, and modern nanomaterials was reviewed. The operating principles of optoelectronic semiconductor devices were analyzed based on physical concepts such as electron–hole pair generation, recombination, the photoelectric effect, electroluminescence, and band gap energy. Comparative analysis was used to examine the functional characteristics of light-emitting, light-receiving, and energy-conversion devices. In addition, modern materials such as silicon, gallium arsenide, gallium nitride, perovskites, organic semiconductors, and quantum dots were considered in terms of their efficiency, speed, and practical applicability.

RESULTS AND DISCUSSION

The operating speed of LEDs is extremely high, and they are capable of switching on and off within nanoseconds. This characteristic makes them highly important not only for lighting applications but also for information transmission technologies (for example, optical signaling and Li-Fi systems).

Their areas of practical application are wide:

• domestic and industrial lighting systems
• displays and screens (phones, televisions, advertising panels)
• automotive headlights and signal lights
• medical devices (phototherapy, diagnostics)
• sensor and indicator systems

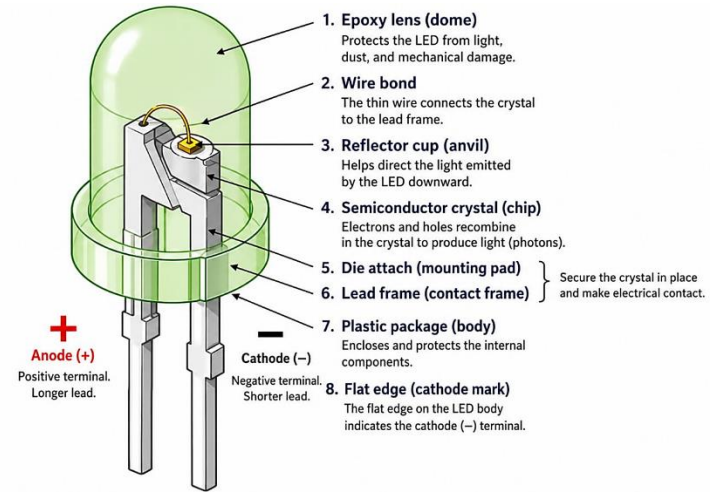
LED technology has become an integral part of modern electronics due to its energy efficiency, long service life, and flexibility. In the future, new directions such as microLED, organic LEDs (OLED), and quantum dot LEDs are expected to further advance this field, enabling the development of even higher-quality and more efficient light sources.

Modern optoelectronic devices have various functions. The most common ones are as follows:

• Light-emitting devices: LED (light-emitting diodes), laser diodes
• Light-detecting devices: photodiodes, photoresistors
• Energy conversion systems: solar panels
• Signal transmission elements: components of fiber-optic communication systems

These devices are mainly based on semiconductor materials such as silicon (Si), gallium arsenide (GaAs), and gallium nitride (GaN). In particular, wide bandgap materials are distinguished by their ability to operate efficiently at high temperatures and high voltages.

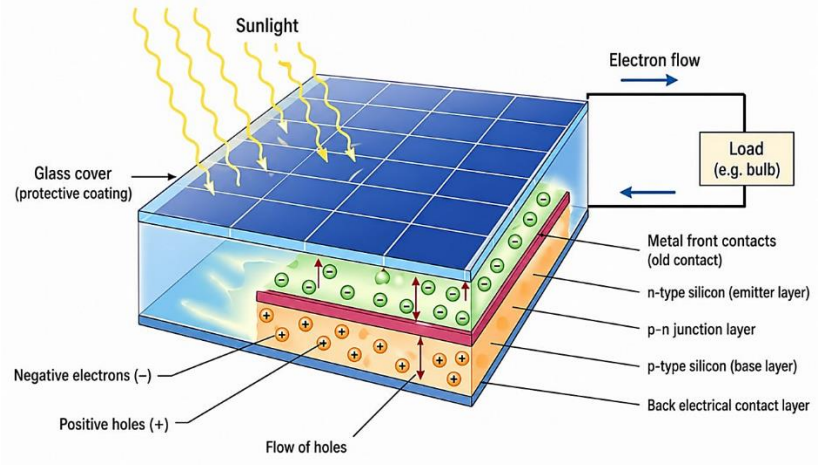
In recent years, optoelectronics has been developing rapidly. This is due to the emergence of nanostructures, quantum dots, two-dimensional (2D) materials (such as graphene), and artificial intelligence–based optimized designs. As a result, devices are becoming smaller, more energy-efficient, and significantly faster in operation. New-generation laser diodes play an important role in high-frequency signal transmission, which contributes to the development of 5G and future 6G technologies.



Ris 3. Structure of an LED (Light-Emitting Diode)

The application areas of optoelectronics are very broad. In telecommunications, large volumes of data are transmitted at high speed through fiber-optic communication. In medicine, laser devices are used in surgical procedures, diagnostics, and therapy. In industry, optical sensors increase the accuracy of automation systems. In addition, optical computing technologies have significant potential in artificial intelligence systems; they may become faster and more energy-efficient than conventional electronic computing. Optoelectronics is one of the key directions in the development of modern technologies, and in the future it will play a decisive role in the creation of high-speed communication systems, intelligent medical devices, and energy-efficient systems.

In the field of optoelectronics, semiconductor devices are emerging as one of the most important areas of modern science and technology. In recent years, nanoscale structures—particularly quantum dots and various nanomaterials—have significantly improved device efficiency. This is based on the quantum confinement effect: as the size of particles decreases, their energy properties change, and as a result, the processes of light emission and detection become much more efficient.



Ris 4. Structure and Operating Principle of a Solar Cell

Structure of a Solar Cell

A solar cell is a semiconductor device that converts light energy into electrical energy. Its main structure consists of the following components:

- p-type semiconductor layer – a layer rich in holes (positive charge carriers)
- n-type semiconductor layer – a layer rich in electrons (negative charge carriers)
- p–n junction – the boundary between p-type and n-type materials, which is the active region of the device
- Front metal contact grid (finger electrodes) – collects and transports generated electrons while allowing light to pass through
- Back metal contact – provides electrical connection on the rear side
- Anti-reflective coating – reduces light reflection and increases light absorption efficiency
- Protective glass layer – protects the cell from environmental effects and ensures mechanical stability

Operating Principle of a Solar Cell

The operation of a solar cell is based on the photovoltaic effect:

a. When sunlight (photons) falls on the semiconductor material, it excites electrons from the valence band to the conduction band, creating electron–hole pairs.

b. The internal electric field at the p–n junction separates these charge carriers: electrons move toward the n-type region, and holes move toward the p-type region.

c. This separation of charges creates a potential difference (voltage) across the device.

d. When an external circuit is connected, electrons flow through the circuit, generating electric current

Among next-generation materials, perovskites and organic semiconductors occupy a special place. Compared to conventional materials, they are cheaper, simpler to manufacture, and enable the creation of flexible devices. For this reason, they are widely used in solar panels, LEDs, and other optoelectronic systems.

Another important direction of technological development is the integration of electronic and optical components into a single chip. Such integration increases data transmission speed, makes systems more compact, and reduces energy consumption. This is of great importance in modern communication and computing technologies.

The operation of semiconductor devices depends on their physical properties. They have valence and conduction bands, and the energy gap between these bands determines the main parameters of the device. At the same time, they are sensitive to external factors such as light, temperature, and electric fields, which makes them suitable for the development of various sensors and detectors.

Modern devices are manufactured at very small scales and operate at high speeds, which further increases their efficiency. In general, optoelectronic devices are characterized by high speed, energy efficiency, and wide applicability. New materials based on nano- and quantum technologies are further advancing this field, paving the way for the development of more efficient, compact, and intelligent systems in the future.

CONCLUSION

Optoelectronics has emerged as one of the strategic directions of modern scientific and technological development, focusing on the creation of highly efficient devices based on the interaction and integration of light and electrical phenomena. In this field, through in-depth

investigation of the fundamental properties of semiconductor materials and their application in practical technologies, systems characterized by high precision, fast response, and energy efficiency are being developed. Modern approaches show that the advancement of optoelectronic devices is directly related not only to the improvement of material quality but also to their structural and functional-level optimization. In particular, micro- and nanoscale engineering solutions significantly expand the ability to control device parameters and considerably extend their physical limits.

At the same time, the development of multifunctional and integrated systems is transforming optoelectronics from a set of individual devices into a complex technological platform. Today, an interdisciplinary approach plays a crucial role in the advancement of this field. The combination of physical laws, electronic principles, and advanced materials technologies is enabling the creation of next-generation devices. This not only improves existing technologies but also lays the foundation for the development of entirely new systems with advanced functional capabilities.

From a future perspective, optoelectronics is expected to play a decisive role in high-speed data transmission, energy-efficient systems, and the development of intelligent and adaptive devices. Therefore, deep scientific research and continuous innovation in this field remain one of the key drivers of global technological progress.

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INTERPRETATION OF ELASTIC AND INELASTIC MOLECULAR COLLISIONS IN MOLECULAR PHYSICS IN CHEMICAL SCIENCE

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https://doi.org/10.5281/zenodo.20065623

Abstract. *This article provides a theoretical analysis of elastic and inelastic molecular collisions within the framework of molecular physics and explains their interpretation in chemical science. Using the kinetic theory of gases, this paper examines the motion of molecules, their interactions, and collision processes. In the case of elastic collisions, the laws of conservation of momentum and kinetic energy are explained, while in the case of inelastic collisions, the conversion of energy into other forms is explained. Furthermore, the role of inelastic collisions in chemical reactions is analyzed, and the fundamentals of collision theory and activation energy are discussed. This paper reveals the close relationship between molecular physics and chemistry.*

Keywords: *molecular physics, molecule, elastic collision, inelastic collision, kinetic energy, momentum, kinetic theory of gases, chemical kinetics, activation energy, collision theory, diffusion, energy exchange, chemical reaction.*

Introduction

In recent years, new branches of physics - such as plasma physics, particle physics, semiconductor physics, biophysics, solid-state physics, and heliophysics - have been developing intensively. The emergence and study of these new fields lead to the formation of new branches of technology. In turn, the advancement of engineering sciences contributes to the improvement of research methods in physics. For example, the creation of powerful accelerators for charged particles is possible only due to the high level of technological development. Furthermore, if we consider the historical development of physics, we can observe that the progress of science is directly related to the development of production. This is because the achievements of physics are directly applied in engineering and technology, which, in turn, play a crucial role in advancing industrial production [1]. The study of physics, its relationship with other sciences, and its application in practice are based on the intellectual evolution of discoveries and concepts from ancient times to the present day. Many physical and chemical ideas used today can be traced back to early civilizations. To understand how the world around us is structured, it is essential first to study the laws of physics that form its foundation. Physics is not merely a collection of complex formulas; it is reflected in every object we observe. It studies all phenomena and processes occurring in nature, making it inseparable from everyday life. Physics is sometimes referred to as a “fundamental science” because other natural sciences - such as biology, geology, and chemistry - describe only specific classes of material systems that obey the laws of physics. For example, chemistry studies atoms, the substances formed from them, and the transformation of one substance into another. The chemical properties of substances are determined by the physical properties of atoms and molecules, as described in fields of physics such as molecular physics, thermodynamics, electromagnetism, and quantum physics. The transformation of substances into

other substances is called a chemical process, and chemistry studies these processes. Therefore, chemistry is the science of the composition, structure, properties of substances, and their transformations, as well as the changes that occur during these processes. Since physical changes occur simultaneously with chemical changes in substances, chemistry is closely interconnected with physics [2].

Molecular physics and chemistry are closely interconnected in the study of the structure of matter, its properties, and its transformations. The collisions between molecules determine many physical and chemical properties of substances. In particular, elastic and inelastic collisions play a significant role in the kinetic theory of gases, reaction rates, and energy exchange processes. Molecular physics studies the molecular structure of matter and the laws governing molecular motion. This field is based on the principles that matter consists of molecules, that molecules are in constant random motion, and that they interact with one another. According to the kinetic theory of gases, molecules continuously collide with each other, and it is precisely these collisions that determine macroscopic quantities such as pressure and temperature. Molecular collisions can be classified as elastic or inelastic. An elastic collision is defined as a process in which the total kinetic energy of the system is conserved during the interaction. Its main characteristics include the conservation of momentum and kinetic energy, while any deformation that occurs during the collision is temporary [3].

In chemistry, elastic collisions are applied in explaining gas pressure, diffusion processes, and the ideal gas model. The collisions between moleculesthat is, their interactions and impacts - are essential for explaining many physical and chemical properties of substances. They play a particularly important role in the molecular-kinetic theory (MKT). All matter (gases, liquids, and even solids) consists of molecules that are in constant motion, continuously colliding with one another while changing their direction and velocity. During these collisions, energy is exchanged, and both velocity and direction are altered. These collisions may be elastic, where energy is conserved, or they may lead to chemical reactions under certain conditions. Such collisions directly influence gas pressure: a higher frequency of collisions results in higher pressure, while fewer collisions correspond to lower pressure. Temperature also affects molecular motion - an increase in temperature causes molecules to move faster. Additionally, diffusion, which is the mixing of molecules of different substances, occurs as a result of these molecular collisions [4].

Morphology

In molecular physics, the interpretation of elastic and inelastic molecular collisions in chemistry represents a complex scientific concept composed of several fundamental components. A morphological analysis of this topic helps to clarify its content in a precise and systematic manner. First of all, the term *molecular physics* is derived from the word “molecule” with the addition of the suffix “-ar,” and it refers to the branch of physics that studies physical processes related to molecules. The molecule itself is one of the fundamental concepts in both chemistry and physics, representing the smallest particle of a substance. The study of elastic and inelastic molecular collisions is an important scientific direction that has been extensively investigated in both molecular physics and chemistry. This problem was initially explored in depth during the development of the kinetic theory of gases, where the random motion and interactions of molecules provided the basis for explaining the macroscopic properties of matter [5]. In classical physics, these processes are explained based on the laws of conservation of momentum and energy. In particular, elastic collisions of gas molecules played a crucial role in the development of the ideal

gas model. Later, inelastic collisions were also studied, revealing that part of the energy is transformed into internal energy, heat, or other forms.

In chemistry, this issue has been developed within the framework of chemical kinetics. Based on collision theory, the mechanism of chemical reactions is explained by establishing the necessary conditions for effective molecular collisions namely, sufficient energy (activation energy) and proper spatial orientation. In this context, the theory proposed by Svante Arrhenius plays a significant role. Furthermore, studies in the field of physical chemistry have extensively examined intermolecular interactions, energy exchange processes, and the factors influencing reaction rates [6]. In modern scientific research, collision processes are being analyzed more deeply through molecular dynamics simulations and quantum chemical methods. Although this topic has been addressed from various perspectives in the textbooks and scientific works of both local and international scholars, a comprehensive analysis of elastic and inelastic collisions based on the integration of molecular physics and chemistry remains one of the most relevant issues.

The rapid development of modern natural sciences requires an in-depth study of the microscopic properties of matter. In particular, the integration of molecular physics and chemistry is of great scientific and practical importance for understanding molecular motion, interactions, and energy exchange processes. From this perspective, the study of elastic and inelastic molecular collisions remains one of the most relevant research topics. Future technologies will increasingly rely not on naturally available materials, which may not always meet reliability and durability requirements, but on synthetic materials designed with predetermined properties. In the creation of such materials, alongside advances in chemistry, physical methods of influencing matter—such as electron, ion, and laser beams; extremely strong magnetic fields; ultra-high pressures and temperatures; and ultrasonic waves—are becoming increasingly important. These approaches make it possible to obtain materials with extreme properties and to develop fundamentally new methods of material processing that can significantly transform modern technology. The close interconnection of physics with other sciences, particularly chemistry, is explained by the fundamental nature of physics, as it reveals the general laws of nature that govern processes and motion both in our immediate surroundings and throughout the universe [7].

Results

Elastic and inelastic collisions form the foundation of the kinetic theory of gases and play a crucial role in explaining the macroscopic properties of substances, such as pressure, temperature, and changes in volume. At the same time, inelastic collisions serve as a key factor in explaining the mechanisms of chemical reactions. This is because such collisions involve energy exchange between molecules, resulting in the formation of new chemical bonds or the breaking of existing ones. In modern fields such as industrial chemistry, pharmaceuticals, nanotechnology, and energy, a deep understanding of reaction kinetics is essential for designing efficient processes. This, in turn, requires a thorough investigation of the nature of molecular collisions, particularly their elastic and inelastic characteristics. Furthermore, understanding molecular processes occurring in the atmosphere is important for addressing environmental challenges. Therefore, from the perspective of molecular physics, the study of elastic and inelastic molecular collisions remains highly relevant both theoretically and practically, and it is closely connected with many branches of chemistry [8]. In inelastic molecular collisions, a portion of the kinetic energy is converted into other forms of energy, such as internal energy, heat, or deformation. These collisions can be classified as partially inelastic or perfectly inelastic, in which the colliding bodies move together after the interaction. During such collisions, molecules may become excited, their electronic

energy levels may change, and heat may be either released or absorbed. In chemistry, chemical reactions occur as a result of inelastic collisions; the concept of activation energy is directly related to this process, as chemical bonds between molecules are broken or formed. For example, the necessary conditions for a reaction include the occurrence of collisions, sufficient energy (activation energy), and proper molecular orientation.

Comparison of Elastic and Inelastic Collisions

Property	**Elastic**	**Inelastic**
Energy conservation	**Yes**	**No**
Momentum conservation	**Yes**	**Yes**
Energy exchange	**No**	**Yes**
Effect on chemical reactions	**Low**	**Very high**

In chemical kinetics, collision theory is used to study the rate of chemical reactions. According to this theory, the reaction rate depends on the number of collisions, the energy of the collisions, and the orientation of the molecules [9].

Conclusion

In conclusion, elastic and inelastic molecular collisions play a fundamental role in explaining the behavior of matter in molecular physics, and these concepts directly contribute to understanding reaction mechanisms in chemistry. In elastic collisions, when molecules collide, the total kinetic energy of the system is conserved. As a result, only the velocity and direction of the molecules change, while their internal structure, including chemical bonds, remains unaffected. Therefore, elastic collisions are mainly important for explaining physical phenomena such as gas pressure, diffusion, and thermal motion. From a chemical perspective, such collisions do not initiate reactions and are thus considered ineffective. In contrast, inelastic collisions involve a different situation. In these collisions, a portion of the kinetic energy is transformed into internal energy, such as vibrational or rotational energy. Most importantly, if the colliding molecules possess sufficient energy (activation energy) and have the correct spatial orientation, chemical bonds may break and new bonds may form. As a result, new substances are produced, and a chemical reaction occurs [10]. Based on this, the concept of *effective collision theory* has been developed in chemistry, which explains that chemical reactions occur only as a result of those inelastic collisions that meet specific conditions. In general, distinguishing between elastic and inelastic collisions enables a deeper understanding of molecular-level processes, the explanation of reaction rates, and the analysis of the physical properties of substances. Furthermore, this theory establishes that the rate of a reaction depends not only on the frequency of collisions but also directly on the energy and spatial orientation of the colliding particles. That is, for an effective collision to occur, molecules must possess sufficient activation energy and approach each other with proper orientation. In this regard, factors such as temperature, pressure, concentration, and the presence of catalysts have a significant influence on reaction kinetics. Consequently, effective collision theory serves as an important scientific foundation for controlling chemical processes, optimizing industrial technologies, and developing new materials. These concepts are essential not only in theoretical physics and chemistry but also in applied chemistry, materials science, and the understanding of biological processes.

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SYNTHESIS OF HYDROGENATION CATALYSTS FOR THE HYDROPROCESSING OF PETROLEUM FRACTIONS

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https://doi.org/10.5281/zenodo.19563616

Abstract. *Various aspects of the synthesis of catalysts for the hydroprocessing of petroleum fractions based on spent alumina adsorbent and kaolin clay are examined, and their influence on catalytic activity is discussed. The study considers the preparation of catalyst supports, their physicochemical properties, and the effect of composition and heat-treatment conditions on the performance of the resulting catalysts. The feasibility of partially replacing imported aluminum hydroxide with spent alumina adsorbent and kaolin from local raw materials is demonstrated. The obtained catalysts showed satisfactory activity and stability in the hydroprocessing of petroleum fractions and may be recommended for industrial application.*

Keywords: *catalysts, catalytic activity, hydroprocessing, aluminum oxide, dearomatization, carbonization of supports, spent adsorbent.*

Introduction

The increasing demand for ultra-clean fuels, combined with the growing share of heavy crude oils with high aromatic hydrocarbon content in petroleum feedstocks, both in Uzbekistan and worldwide, poses serious economic and technological challenges for the modern oil-refining industry. In particular, the demand for middle distillates is steadily increasing, while the quality of available feedstocks is declining. Low-quality petroleum feedstocks, as well as alternative renewable raw materials, require more intensive processing in order to meet the demand for additional ultra-clean motor fuels. Therefore, hydrocatalytic processes are becoming increasingly important in oil refining.

This paper examines various aspects of the use of non-traditional support components in the synthesis of hydrodearomatization catalysts for the processing of petroleum fractions. Aluminum hydroxide, which constitutes the major portion of catalyst mass, is not produced in Uzbekistan. One potential raw-material source of aluminum oxide is the large-scale waste product of the Shurtan Gas Chemical Complex, namely spent alumina adsorbent (OAA). Therefore, a series of studies was carried out to demonstrate the feasibility of replacing up to 60% of imported aluminum hydroxide with OAA and kaolin clay from the Angren deposit. In this system, kaolin serves as a modifier of pore structure and mechanical strength.

Materials and Methods

Catalyst supports were prepared by extrusion after peptization of mixtures of the starting powders (Table 1) with an aqueous HNO3 solution, followed by heat treatment in air or nitrogen.

The samples were characterized using the following instruments: a Carlo Erba mercury porosimeter, a JXA-8800R Superprobe electron microanalyzer (JEOL), a Dron-3 diffractometer, a Q-1500D derivatograph, a Tesla electron microscope, a Specord-75 IR spectrometer, an SP-9 PYE UNICAM atomic absorption spectrometer, and a Chrom-5 chromatograph.

Electronic spectra of the catalysts and adsorbed acid-base indicators, used for surface-property evaluation according to the method described in reference [5], were obtained using a Hitachi-330 spectrophotometer. The amount of chemisorbed O2 was determined by pulsed gas chromatography after preliminary reduction of the catalysts in H2 at 823 K.

The hydrogenation catalysts were prepared by double impregnation with analogous solutions, with intermediate heat treatment. The hydrogenation performance of the samples was evaluated on the basis of changes in the polyaromatic compound content of the feedstock. The catalysts were tested in a pilot flow unit with a catalyst loading of 150 mL. Hydroprocessing of the deasphalted residual oil fraction and crude kerosene was carried out at a hydrogen pressure of 4 MPa, whereas hydroprocessing of the diesel distillate was conducted at 5 MPa. The reactor temperature was maintained in the range of 573-593 K.

Table 1. Effect of Composition and Heat-Treatment Conditions at 823-873 K on the Specific Surface Area, Carbon Content, and Surface Properties of Supports

Support Code	Composition of Support Components (Calcination Medium)	Ssp., m^2/g	C, %	Surface pKa centers (concentration, mg-eq/g)
1	60% OAA + 40% GOA (air)	160	0.05	-5.6 (0.05); -3.3 (0.15); +1.5 (0.19); +3.8 (0.31); +9.3 (0.01)
2	GOA + 10% kaolin (air)	265	0	-8.2 (0.008); -5.6 (0.08); -3.3 (0.23); +1.5 (0.34)
3	60% OAA + 30% GOA + 10% kaolin (air)	109	0.03	+1.5 (0.01); +3.8 (0.18); +6.1 (0.37); +9.3 (0.014)
4	OAA + 30% kaolin (air)	91	0	+1.5 (0.13); +3.8 (0.23); +6.1 (0.25); +9.3 (0.01)
5	GOA (air)	275	0	-6.3 (0.01); -5.6 (0.07); -3.3 (0.24); +1.5 (0.48); +3.8 (0.50)

Results and Discussion

The GOA used for sample synthesis consisted of a mixture of boehmite and pseudoboehmite and exhibited weak acidic surface sites with pKa values ranging from +3.8 to +6.1. OAA contained 30-50% γ-Al2O3, 5-15% α-Al2O3, and 40-60% boehmite with crystal sizes ranging from 10 to 100 nm. The impurity content varied within the following ranges (%): Na2O, 1.7-2.0; Cl, 0.3-0.8; CaO, 0-0.5; TiO2, 0.3-0.5; and V2O5, 0.4-0.6. In addition to weak acidic sites, the OAA surface also contained basic sites with pKa values up to +10.3. Kaolin contained 45-70% kaolinite and 20-30% quartz. The main impurities were P2O5, SO3, K2O, CaO, FeO, and BaO. The acidity of kaolin was within the pKa range from +1.5 to +3.8.

The use of OAA has specific features related to its role in polyethylene production. Fresh adsorbent is used to purify polymer solutions from polymerization catalyst residues such as VOClx and TiClx, present in the form of chelate complexes with deactivators and associated compounds, by chemisorption at 533-583 K under high pressure. The total carbon content of the chemisorbed substances ranged from 1.5 to 4.5% of the OAA mass.

It was found that heating 100 g of OAA granules to 513 K in a reactor resulted in the desorption of 4.3 g/100 g of water and 0.6 g/100 g of unidentified organic substances, with absorption bands corresponding to -CH2 and -CH3 groups (2930, 2873-2843 $cm^{-}1$), as well as C=O, C-O-H, C-O, and O-H groups (1720, 1410, 1282, and 933 $cm^{-}1$) in the IR spectra of the gas

phase. The evolution of CO and CO2 began above 520 K, reached a maximum concentration at 833-923 K, and was completed within 18 hours at 973 K. In total, 5.9 g of CO, 4.8 g of CO2, 1.6 g of HCl, and 0.2 g of H2O were released from 100 g of OAA in the temperature range of 833-973 K.

The weight loss (ΔP) due to H2O removal from fresh adsorbent in the endothermic region at 393-453 K was less than 2%, whereas complete conversion of boehmite to Al2O3 resulted in a weight loss of 7.2% (Fig. 1, curve 1).

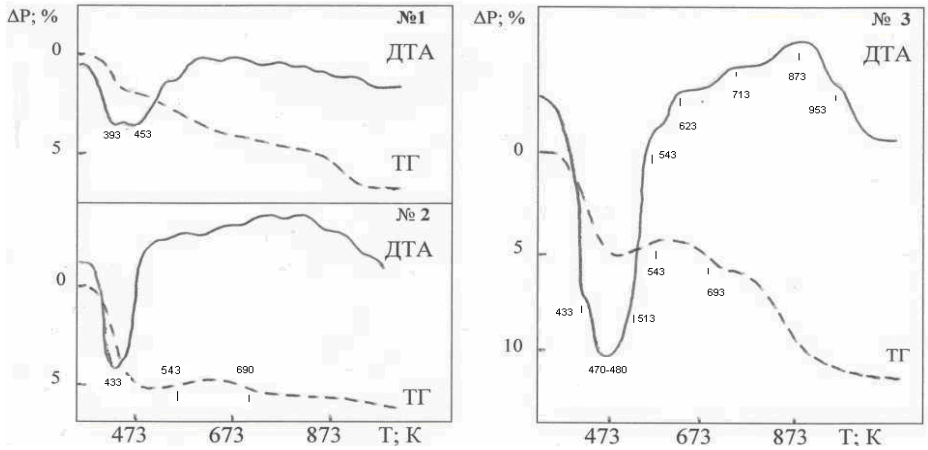


Figure 1. Thermograms of fresh adsorbent (1); OAA sample with 1.5% C (2); and OAA sample with the maximum content of chemisorbed substances, 4.5% C (3).

Under the conditions of thermogram recording using 100 mg of OAA powder, an endothermic effect accompanied by a weight loss (ΔP) of 5% was observed at 433-513 K, and the depth of this effect was proportional to the carbon content. The increase in weight by 1-2% in the exothermic region at 543-693 K can be explained by oxygen addition to chemisorbed substances, which exceeded the simultaneous desorption of carbon-containing gases and water. At a heating rate of 10 K/min, weight changes (ΔP = 7%) and thermal effects accompanied by the release of heat at 543, 623, 713, 873, and 953 K, as well as the evolution of CO, CO2, traces of H2O, and HCl, were observed for approximately one hour and ceased at 1093 K.

The calculated weight loss during complete oxidation of compounds of the CH3(-CH2-)n-COOH type and chelate complexes of V and Ti, responsible for the presence of 0.6 mg V2O5, 0.5 mg TiO2, and 0.8 mg Cl in 100 mg of OAA, was 7.2% (Fig. 1, curve 3). In this process, approximately 14 mg of O2 should be consumed, and 16.5 mg of CO2, 4.4 mg of H2O, and 0.3 mg of HCl should be released into the gas phase. Differential thermal analysis and thermogravimetry data, together with measurements of H2O, CO, and CO2 formed during heating in air, indicate a stepwise removal of chemisorbed substances from OAA, preceded by oxygen addition and characterized by strong chemical bonding to the adsorbent surface.

The mechanical strength and wide-pore structure of the dearomatization catalyst supports, achieved through the addition of OAA and kaolin, were retained after the application of active metals (Tables 1 and 2).

Table 2. Physicochemical Characteristics of Catalysts Prepared on Various Supports

Catalyst Code	TiO2, %	V2O5, %	WO3, %	NiO, %	CoO, %	MoO3, %	Support Code	Strength, kg/mm	Pore radius, nm (pore	Ssp., m²/g

									volume, cm^3/g)	
Kt-6	0	0	0	1.73	4.2	17.9	3	2.85	3-5 (0.45); 5-15 (0.060); > 90 (0.02)	295.5
Kt-8	0.01	0.03	0	1.70	4.19	17.6	4	3.15	<3 (0.12); 5-7 (0.10); 45-160 (0.32)	109.5
Kt-9	0.02	0.03	0	6.03	0	18.1	4	3.43	<3 (0.10); 5-7 (0.09); 45-160 (0.36)	105.8
Kt-10	0.02	0.02	1.4	5.92	0	17.8	4	3.27	3-4 (0.19); 10-40 (0.35); >120 (0.01)	89.5

With increasing concentrations of active components, the formation of very fine pores intensifies during the thermal decomposition of hydrated nickel (or cobalt) molybdates and tungstates aggregated within the pores of the catalyst precursor during repeated impregnation with combined solutions. Based on the results of sequential extraction with water and aqueous ammonia, it was shown that the proportion of surface Ni(Co) and Mo structures strongly bound to the support and responsible for hydrodesulfurization reactions decreased to 30-60%, depending on the support. The amount of weakly bound Ni, Co, Mo, and W structures possessing the highest hydrogenating capacity increased with the use of OAA and followed the following order: Kt-6 (4.7/24.7) ≤ Kt-8 (11.5/23.5) < Kt-9 (12.6/24.2) ≤ Kt-10 (12.7/25.2).

An increase in the relative intensity of absorption bands corresponding to nickel and/or cobalt molybdates with octahedral cation coordination was observed. NiTd2+ and CoTd2+ ions in spinel structures, as well as NiWO4 in the composition of Kt-10, were not detected spectrally (Fig. 2, curves 8 and 9). Laboratory rig testing of the comparative stability of catalysts prepared on supports calcined in air and nitrogen during hydrotreating of the residual fraction boiling above 773 K revealed no trend toward progressive activity loss after 500 hours of testing and three experimental regenerations of catalysts on a carbonized support.

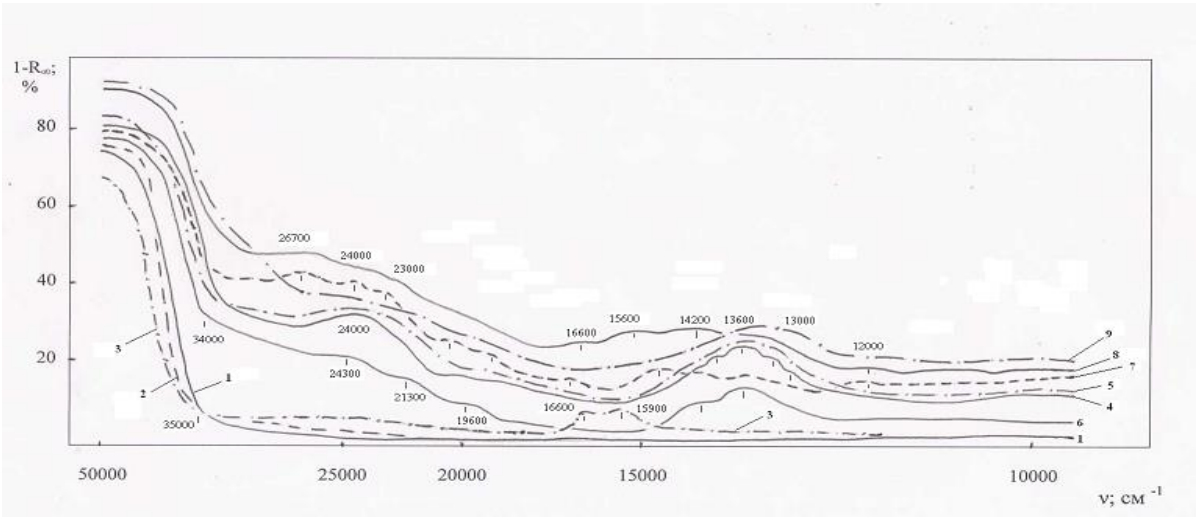


Figure 2. Electronic spectra of catalysts: 1 - Kt-1; 2 - Kt-3*; 3 - Kt-17; 4 - Kt-14; 5 - Kt-16*; 6 - Kt-13*; 7 - Kt-7; 8 - Kt-8; 9 - Kt-10.

These scientific approaches made it possible to develop and implement a number of catalysts based on OAA and kaolin. Since 2012, a pilot run of a dearomatization catalyst has been carried out at the Fergana Oil Refinery on the G-24 unit as part of a multilayer catalytic system based on an industrial AKM catalyst. No increase in pressure drop was observed. The quality of the resulting base oils fully complied with enterprise standards. Full-scale loading of the catalyst into the reactors of the Fergana Oil Refinery is planned.

Conclusions

1. A combination of physicochemical methods showed that catalysts prepared using OAA and kaolin are comparable in activity and stability to catalysts based on aluminum hydroxide and can be recommended for use in industrial reactors.
2. Although the technology for producing supports containing OAA is somewhat more complex, it makes it possible to obtain catalysts with enhanced activity in the removal of sulfur compounds and impurity metals.
3. Pilot batches of the developed catalysts showed positive results under industrial conditions at the G-24 unit during the production of base oils.

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RESEARCH OF LIMIT LOADS IN OPPOSITE FLOWS IN ABSORPTION PURIFICATION OF GAS AND LIQUID FLOWS OF NATURAL GASES

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https://doi.org/10.5281/zenodo.19705122

Abstract. *It has been scientifically substantiated that during the absorption purification of gas and liquid flows, the free volume of natural gases decreases during their two-phase movement, and tangential stresses arise on the contact surface of the phases owing to friction during their movement. The results of this study proved that in such a process, when the gas flow moves upward, the gas velocity decreases because of the backward movement of the flow and the force of gravity of the liquid. The obtained results prove that with a further increase in the gas velocity, the liquid begins to grow into the nozzle, and the possibility of determining it as a turbulence mode of a two-phase system on the surface of the hydrodynamic regime has been proven. The processes of its application in the purification of natural gases at the "Shurtan Oil and Gas Production Department," "Mubarek Gas Processing Plant," "Shurtan Gas Chemical Complex," and "Ustyurt Gas Chemical Complex" Ustyurt Gas Chemical Complex have been investigated owing to its high selectivity.*

Keywords*: two-phase, curtain mode, packing, emulsification mode, packing accumulation, standing mode, transparent packing.*

Introduction.

In the two-phase motion of a gas and liquid, the free volume decreases, and as a result of friction, tangential stresses arise on the contact surface of the phases. During two-phase motion, the interaction between the phases leads to an increase in the hydraulic resistance of the AP compared that with of the dry (non-irrigating) nozzle. This interaction can be neglected only at low phase speeds. When the gas and liquid move in opposite directions, four different hydrodynamic regimes are distinguished depending on the flow velocity (Fig. 1).

The first (Section A), called the curtain mode, occurred at low gas and liquid loads. In this mode, the phase interaction is insignificant, and the amount of fluid held (US-holding capacity) does not depend on the gas velocity. Section A, which represents the resistance of the irrigation nozzle, is a parallel line for dry nozzle I and is located above the nozzle with increasing irrigation density. Some researchers[1] have noted that this mode is one.

Above the 1st braking point, an intermediate fluid regime can occur during movement (Fig. 1, section B). The liquid covered the nozzle in the form of a thin flowing film and separate streams. Interfacial interactions occur on the surface of the film and liquid flows and at the points where the liquid contacts the individual elements of the nozzle. In film and fluid flows, a slowdown is observed with the formation of individual gas-flow vortices [2].

With a further increase in gas velocity, the liquid began to grow on the nozzle (point of suspension 2), whereas the opposite flow was maintained by the moving gas. An increase in US with an increase in gas velocity led to a decrease in the free volume of the nozzle and a rapid increase in resistance. The liquid and gas phases interact on the surface of the turbulent fluid film

and can therefore be defined on the surface of the hydrodynamic regime as the turbulent regime of a two-phase system (Section B).

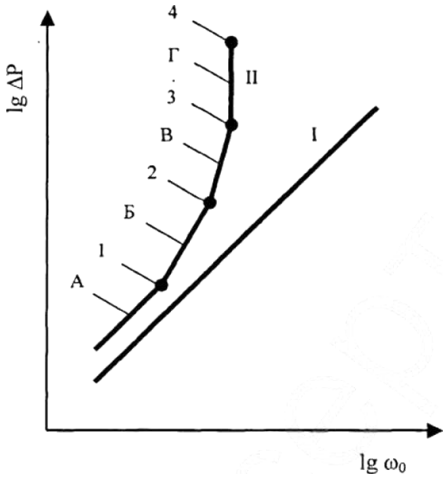


Figure 1 - Hydrodynamic regimes for a two-phase system in the columns of a two-tailed nozzle and their transition points:
I - for dry nozzles, II - during irrigation; A - curtain mode; B-intermediate mode; B-turbulence mode of the two-phase system; G-emulsification mode; 1 - stability point; 2 - hanging point; 3 - phase acceleration point; 4 - suffocation point.

Further accumulation of liquid in the nozzle and the interaction between the flows and wetted surface of the nozzle led to its transition into its volume. The accumulation of liquid primarily began at the bottom of the nozzle and gradually spread throughout the entire height. This is characterized by the emergence of a fundamentally new hydrodynamic regime: the emulsification regime (Section G).

Emulsification mode, a field of free enhanced turbulence, occurs in the packing columns after the phase intensification point. Increased turbulence in each phase of the packing volume leads to turbulent pulsations on the phase separation surface. In this mode, the concept of dispersed and continuous phases loses its meaning because the phases are constantly inverted, transforming into gas or liquid, continuous or dispersed phases. In this case, the phases pass through countless small whirlpools[2].

Under such conditions, a stable hydrodynamic system of "emulsified" liquid exists, in which gas vortices arise and move while penetrating the circulating liquid, in which liquid vortices also arise and move. Unlike the first two points (gas stability point and liquid suspension point), the acceleration point is always sharply visible and well-defined.

According to the studies of Planovsky and Kafarov [3] and several other authors [4, 5, 6], the choking mode corresponds to the maximum efficiency of the nozzle column. The high efficiency in the choking mode is explained by the large contact area of the phases, which is determined not by the geometric surface of the nozzle but by the conditions of the impacts.

The 4th choking point corresponds to conditions in which the height of the gas-liquid (vapor-liquid) emulsion layer is greater than the height of the packaging layer, and a liquid layer accumulates above the nozzle, which is a foam layer with sedimentary mixing.

The final mode (cultivation mode) occurs when the gas velocity exceeds the value corresponding to the countercurrent mode. In this case, intensification of the secondary phase occurs: the gas again transforms into a continuous phase, and the liquid, along with the gas, is carried out from the apparatus, mainly in the form of splashes. Simple filling irrigation was performed.

This mode is accompanied by a sharp decrease in the intensity of mass transfer. The access mode is not used and is therefore unexplored. According to [3], in this mode, the increase in resistance slows down, and the curve of DR's dependence of the DR on the gas velocity proceeds

with approximately the same slope as in the curtain mode. The point corresponding to the transition to the input mode characterizes the maximum load of the device.

Materials and Methods

Experimental studies by many authors [2, 7, 8, 9] on the determination of the suffocation point were determined by the following equations:

1) With an increase in irrigation density, suffocation occurred at a lower gas velocity. In the absence of gas movement, a dependence was observed at high irrigation densities.

2) At the same irrigation density, the gas velocity corresponding to choking is higher at higher values of the equivalent nozzle diameter.

3) With the same dimensions of the packing elements, the lower the load limit for gas and liquid, the lower is the empty volume of the packing.

For packed columns, the critical state is considered to be maintained (accumulation of liquid in the packing) or evaporation of the packing (when the liquid layer accumulates over the winding, which is a foam layer with rapid mixing) [2].

At the limit load of the column, the final loads of the packing columns are determined according to the same laws as those of traditional packing columns; however, in most cases, the beginning of the suspension mode is considered an important point in the operation of the packing [2, 9].

Thus, considering the foregoing, the objectives of studying the maximum loads of the developed two-tailed packing column include:

The gas phase velocity corresponding to the beginning of the suspension regime in the layer of the two-tailed nozzle column, as well as other studied nozzles (for comparison with the usual: an irregular nozzle made of angular, X-shaped, and Rashig rings, and a column of two-tailed nozzles) were determined by the gas flow and liquid phase.

- A mathematical model is found that adequately describes the results obtained from the experimental studies.

According to the adjustment shown in Fig. 1, the velocity of the gas phase in the entire cross-section of the column was determined, corresponding to the start of the holding mode. The obtained data are presented in table.

The values of the gas phase velocity corresponding to the hanging mode of the Rashig rings for the nozzle were calculated using the generally accepted Beyne-Hougen equation [2, 8, 9, 10, 11] for the experimental conditions:

$$\lg\left[\frac{\omega_r^2 \cdot f}{g \cdot \varepsilon_{CB}^3} \cdot \frac{\rho_r}{\rho_æ} \cdot \mu_æ^{0,16}\right] = \hat{A} - \tilde{N} \cdot \left(\frac{W_{Æ}}{W_r}\right)^{0.25} \cdot \left(\frac{\rho_r}{\rho_æ}\right)^{0.125} \quad (1)$$

here ω_r - gas velocity in the entire column cross-section, m/s;

ε_{CB} - Free volume of packaging, m^3/m^3;

f - specific surface area of the nozzle per unit volume, m^2/m^3.

ρ_r, $\rho_æ$ - density of gas and liquid phases, kg/m^3; - dynamic viscosity of the liquid phase, Pa-s; W_r,

W_J - mass flows of gas and liquid phases, kg/ (m-hour);

B and C - corresponding coefficients for different types of nozzles.

For Raschig rings of the selected size (ceramic, 25x25x3), according to various sources, the following data are provided. [2, 8, 9, 11]: = 0,74 m^3 / m^3; f = 200 m^2 / m^3.

Coefficients of equation 3.1 for the condition of the beginning of the gas suspension regime in the layer of the nozzle column [12]: B = - 0,073 and C = 1,75.

Conducting a series of parallel experiments using blocks of a transparent nozzle column according to the method described in Section 3.5 of this dissertation for the studied continuous nozzles showed that the beginning of the gas-phase suspension mode is determined uniquely within the range of the gas and liquid phase flow rate measurement error of no more than 3% (Table 1, Appendix A). Thus, it can be assumed that the values of the gas phase velocity in the entire cross-section of the experimental column, presented in Table 1 (Appendix A), can be completely reliably repeated.

Results and Discussion

The graphs in Fig. 1 show that the velocity of the beginning of the suspension mode in bi-tailed and angular nozzles between the most common gas and liquid loads is practically the same (rows 1 and 2). This circumstance can be explained by the anatomical structure of the column of the tested nozzles. Double-tailed and simple-angled nozzles also have a strictly defined cellular structure of the nozzle column structure. The gap size for both nozzles was 0.015 m.

According to the experimental values of the critical velocity in the entire cross-section of the column for the tested nozzles, presented in Table 1, graphical dependencies are constructed in Fig. 2.

Data on gas phase velocity ω_r corresponds to the beginning of the hanging mode in the full section of the column.

Table 1

($W_{Æ}$ / $W_{r)}$	L/G	Double-tailed nozzle	X-shaped nozzle	Angular nozzle	Rashig rings
1	2	3	4	5	6
5,359	0,0065	1,177	0,969	1,159	0,939
5,824	0,0070	1,146	0,946	1,127	0,914
6,306	0,0076	1,116	0,923	1,097	0,889
6,807	0,0082	1,087	0,902	1,069	0,866
7,327	0,0088	1,059	0,882	1,042	0,843
8,834	0,0106	0,990	0,831	0,974	0,788
9,429	0,0114	0,967	0,813	0,950	0,768
10,049	0,0121	0,944	0,796	0,927	0,750
10,581	0,0128	0,925	0,782	0,909	0,735
11,371	0,0132	0,900	0,772	0,896	0,714
15,252	0,0184	0,798	0,686	0,784	0,633
20,235	0,0249	0,705	0,609	0,686	0,558
26,006	0,0313	0,627	0,553	0,615	0,495
33,475	0,0410	0,553	0,491	0,537	0,436

41,721	0,0503	0,492	0,446	0,482	0,387
52,300	0,0615	0,434	0,404	0,431	0,340
62,909	0,0758	0,389	0,362	0,381	0,305
85,979	0,1048	0,320	0,302	0,310	0,250
106,510	0,1282	0,277	0,268	0,271	0,216
134,369	0,1599	0,235	0,233	0,232	0,183
174,332	0,2102	0,194	0,194	0,188	0,150

From the experimental data presented in the form of graphs in Fig. 2, it can be seen that the X-shaped nozzle has a smaller range of maximum loads for gas and liquid, which is due to the design features of the nozzle. Thus, with the equality of the total area of the gap gaps, the width of the gaps marked on the X-shaped nozzle was 0.01 m.

The speed of starting the gas phase retention mode in the two-tailed nozzle device is 19% higher in the studied range, it should be noted that with an increase in the L/G ratio, the difference in the permissible gas velocity values decreases.

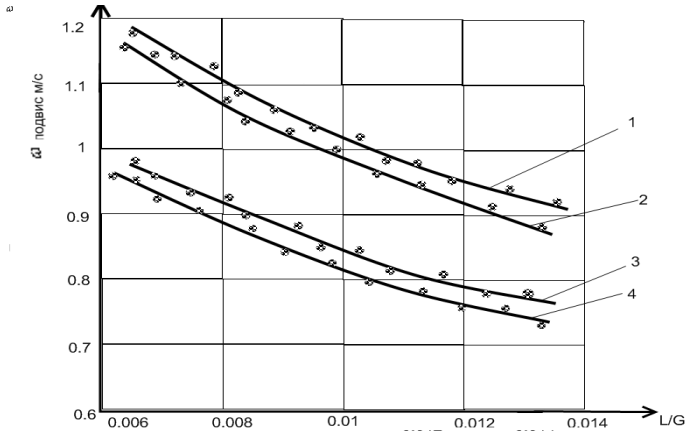


Figure 2. Comparison of initial suspension speeds in different nozzles.
1 - two-tailed nozzle; 2 - angular column; 3 - X-shaped nozzle; 4 - Rashig rings.

Conclusion

When comparing the values of the gas phase velocity corresponding to the beginning of the suspension mode of suspension Re in the two-tailed gas-phase nozzle device with the calculation for the Rashig rings, the difference was found to be 20–22%. It should be noted that with an increase in the load of the liquid phase, the difference in the values of the suspension velocities of the two-tavr nozzle device and the Rashig rings increased.

The experimental data presented in the form of graphs show that the X-shaped nozzle has a smaller range of maximum loads for gas and liquid flows owing to the design features of the nozzle. Thus, with the equality of the total area of the gap gaps, the width of the gaps marked on the X-shaped nozzle was 0.01 m.

The speed of starting the gas-phase shutdown mode in the two-tailed nozzle device was 19% higher in the studied range.

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RELATIONSHIPS BETWEEN CHEMICAL COMPOSITION AND MOLECULAR STRUCTURE OF NATURAL SILK FIBERS DETERMINING THEIR OPERATIONAL PROPERTIES

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https://doi.org/10.5281/zenodo.19879052

Abstract. *This study provides a comprehensive analysis of the microstructure, chemical composition, and physicomechanical properties of silk fibers derived from Bombyx mori silkworms. The morphology of the sericin coating and fibroin core was examined using scanning electron microscopy (SEM), and the molecular structures of fibroin, including β-sheet and α-helix conformations, were analyzed based on established structural models. The results indicate that the high hygroscopicity (11–12%) and mechanical strength of silk fibers are closely associated with the specific amino acid sequence and molecular organization within the fibroin protein structure. These structural characteristics contribute to the unique combination of elasticity, strength, and moisture absorption capacity of silk. These findings provide a scientific foundation for the development of advanced functional materials for applications in the textile and biomedical fields.*

Keywords: *silk fiber, fibroin, sericin, SEM analysis, amino acids, hygroscopicity, biocompatibility.*

INTRODUCTION

Today, the growing demand for natural fibers makes the effective use of high-quality and environmentally friendly materials in the textile industry urgent. Among these fibers, silk fiber occupies a special place due to its unique physical and chemical properties. Silk fibers are widely used for various purposes because of their lightness, strength, elasticity, and hygienic properties [1-3]. The main goal of this study is to scientifically analyze the physical and chemical properties of silk fibers and determine their importance in the textile industry. In recent years, the intensification of environmental problems and the introduction of sustainable development principles have further increased the demand for natural fibers in the textile industry [4, 5]. In this process, silk fibers are of particular importance because of their natural origin, high hygienic indicators, and aesthetic properties. Silk fiber is a natural protein fiber produced by silkworms (Bombyx mori), and its main components are fibroin and sericin.

The physical properties of silk fibers, such as strength, elongation, density, smoothness, and hygroscopicity, are important factors in determining the operational qualities of finished products. Simultaneously, its chemical properties, particularly its resistance to the effects of various reactive substances, acids, and alkalis, are of great importance in technological processing [6]. Although some properties of silk fibers have been widely studied in the scientific literature, the issue of their comprehensive and systematic analysis remains relevant [7-9].

The main goal of this research is to scientifically analyze the physical and chemical properties of silk fibers, determine their interrelationships, and substantiate the possibilities of their application in the textile industry. The results of this study will serve to improve the production process of high-quality and competitive products based on natural fibers.

Fibroin is the main component that provides strength and elasticity to silk fibers. It consists mainly of amino acids, such as glycine, alanine, serine, and tyrosine. In contrast, sericin binds silk fibers together and provides them with softness and shine. Silk fiber (Bombyx mori) is one of the oldest and most valuable natural protein fibers. Its high mechanical strength, exquisite luster, and biocompatibility ensure its widespread use in the modern textile industry and biomedicine. The unique properties of silk fibers are due to their special molecular structure and morphology, which require in-depth scientific research in the field of materials science.

This article presents a comprehensive scientific analysis of the microstructure, chemical composition, molecular structure, physical and mechanical properties, and chemical reactivity of silk fibers. The results of this study provide a scientific basis for the effective use of silk fibers and the development of new functional materials.

RESEARCH METHODOLOGY

To determine the physical properties of the silk fiber, the strength, elongation, density, and moisture absorption of the fibers were analyzed. This process was based on the results of standard test methods. In the study of chemical properties, the reaction of silk fibers to the effects of acids and alkalis and structural changes were evaluated based on scientific sources. During the study, comparative analysis, generalization, and systematization methods were used. This study aimed to determine the physical and chemical properties of silk fibers, and a set of theoretical and empirical research methods was used. At the initial stage of the study, local and foreign scientific sources were analyzed, and existing scientific views on the structure and properties of silk fibers were systematized. In the study of chemical properties, the state of silk fiber under the influence of acids, alkalis, and other chemical reagents was studied, and structural changes were evaluated based on scientific literature and experimental data. During the study, analysis and synthesis, comparative analysis, generalization, and systematization methods were used. Based on the results obtained, scientific conclusions were drawn, and the practical and theoretical significance of silk fibers was substantiated.

Table 1 compares the main chemical properties of silk, wool, and cotton fibers.

Table 1. Physicochemical properties of various fibers.

Special	**Silk**	**Wool**	**Cotton**
Main component	Fibroin (protein)	Keratin (protein)	Cellulose (carbohydrate)
Density (g/cm³)	1.30-1.37	1.30-1.32	1.52-1.54
Moisture absorption (%)	11-12	14-16	7-8
Tensile strength (GPa)	0.4-0.6	0.12-0.18	0.3-0.6
Elongation at break (%)	20-30	25-35	7-10

Crystallinity degree (%)	40-50	20-30	60-70
Acid resistance	Medium	Low	High
Alkali resistance	Low	Very low	High

RESEARCH RESULTS AND DISCUSSION

Silk fibers consist of a two-component system: a central fibroin protein and a surrounding sericin glue. The average fiber diameter is on average 15-20 microns. SEM images show that the sericin layer holds the fibers together, while after degumming, a smooth fibroin surface is revealed. The triangular prismatic cross-section of silk endows it with its characteristic elegant luster and maximum light reflection at an angle of 45-60°.

The chemical composition of Silk fibers are composed of two main proteins. 1. Fibroin (silk protein) makes up 70-80% of the fiber. It is the main structural component and provides mechanical strength to the fiber. 2. Sericin (sericin polymer) makes up 20-30% of the fiber. It is a gummy substance that glues fibers together and protects the cocoon. Fibroin protein is a polypeptide chain that consists of 18 different amino acids. The main amino acids and their percentages are as follows: glycine (Gly, G): 42-45% - the most common amino acid); alanine (Ala, A): 28-32% - in second most common); serine (Ser, S): 12-14% - in third most common); tyrosine (Tyr, Y): 4-6%; Valine, Phenylalanine, etc.: 8-10%. The high percentage of Glycine and Alanine provides the crystalline structure of fibroin. The molecular formulas of these two amino acids are as follows:

Glycine: $C_2H_5NO_2$ or NH_2-CH_2-COOH

Alanine: $C_3H_7NO_2$ or CH_3- CH(NH_2)-COOH

The repeating units of fibroin consist mainly of the sequence Gly-Ala-Gly-Ala-Ser, which leads to the formation of a beta sheet structure.

Images obtained using scanning electron microscopy (SEM) show the complex microstructure of the silk fiber. The surface of raw silk fibers is covered with a layer of sericin, which separates the fibers from one another. After the degumming process, the fibroin fibers were exposed, revealing their smooth and shiny surface (Figure 1).

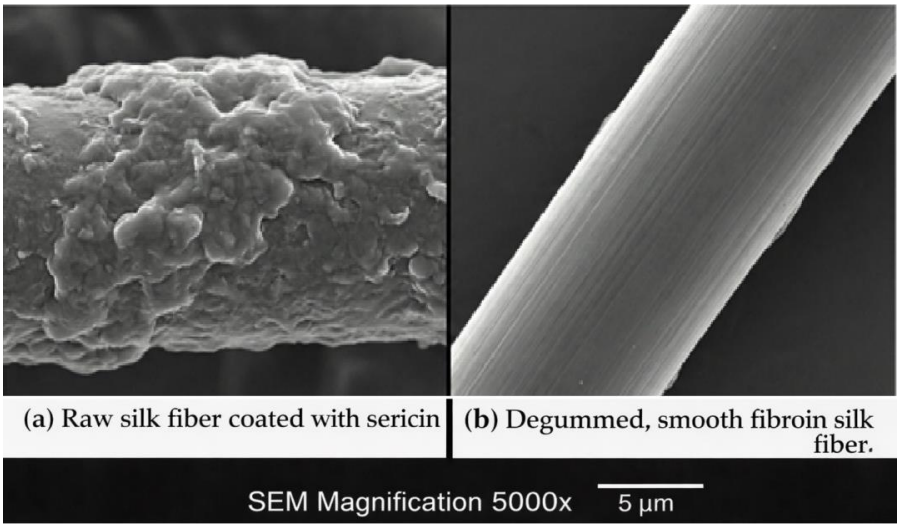


Figure 1. View of the microscopic structure of a silk fiber.

Silk fibers have a fibrillar internal structure. Each fiber is composed of microfibrils, which are composed of nanofibrils and molecular chains. This hierarchical structure endows the fiber with high strength and flexibility.

The molecular structure of silk fibroin includes two main secondary structures: the alpha-helix (α-helix) and beta-sheet (β-sheet) structures. The Alpha-helix structure was dominant in the amorphous regions. In this structure, the polypeptide chain is coiled in a helical shape with 3.6 amino acid residues per turn. Hydrogen bonds form inside the helix, stabilizing the structure. A beta-sheet structure was observed in the crystal spheres. In this structure, polypeptide chains are arranged in parallel or antiparallel fashion and are linked through hydrogen bonds. Fibroin is characterized by an antiparallel beta-sheet structure. The widespread distribution of the beta-sheet structure provides the fiber with high mechanical strength, as this structure allows for the formation of numerous hydrogen bonds between the chains.

The hydrophilic (water-loving) property of silk fibers stems from their protein nature. The hydrophilic groups of amino acids (carbonyl, amino, and hydroxyl) interact with water molecules. Moisture Regain under standard conditions (20°C, 65% relative humidity): Silk: 11-12% (absorbs 11-12% of its weight in water), Wool: 14-16%, Cotton: 7-8%.

The moisture absorption isotherm describes the adsorption properties of the silk fibers. Condensation phenomena were observed in the fiber under high-humidity conditions. The moisture absorption isotherm of the silk fiber (Fig. 3) is associated with the hydrophilic groups of amino acids in its protein structure. The shape of the isotherm is consistent with the BET theory, confirming that at low humidity, monomolecular adsorption occurs at active centers, and at high humidity, multilayer adsorption and capillary condensation occur in interfibrillar micropores. This determines the high hygroscopicity (11-12%) of silk.

During the research, the main physical and chemical properties of the silk fiber were analyzed. The results obtained confirm that silk fiber is a natural fiber with high-quality indicators. Physical studies have shown that silk fibers have high mechanical strength and a sufficient level of elongation. These properties increase the resistance of the fibers to breakage and ensure a long service life of the finished products. In addition, the smooth surface of silk fibers leads to a low coefficient of friction, which improves the aesthetic appearance and comfort of fabrics.

Analysis of the moisture absorption properties showed that the silk fiber has high hygroscopic properties. This property normalizes the heat and moisture exchange in clothing products, providing a favorable microclimate for the human body. When compared with the data presented in the literature, the results of this study confirm that silk fiber has higher hygienic properties than other natural fibers. According to the results of chemical studies, the composition of silk fibers, consisting of fibroin and sericin proteins, determines their chemical activity. Although silk fibers are relatively stable under the influence of acids, protein chains are broken down under the influence of strong alkalis. This requires precautions during the chemical treatment of silk fibers. The use of gentle technological regimes in the bleaching and dyeing processes allows for the preservation of the physical properties of the fibers.

During the discussion, it was found that there is a close relationship between the physical and chemical properties. For example, the chemical composition of fibers directly affects their mechanical strength and their elasticity. The results of this study are consistent with the data from existing scientific sources and confirm that silk fiber is an important raw material for the production of high-quality, environmentally friendly, and competitive products in the textile industry.

CONCLUSION

Complex studies revealed that the physical and chemical properties of silk fibers (*Bombyx mori*) are closely related to their hierarchical molecular structure. Scanning electron microscopy (SEM) analysis showed that the fiber consists of a two-component system, that is, morphological differences between the central fibroin protein and the sericin glue surrounding it. In the theoretical part of the study, the moisture absorption isotherm of silk fiber was analyzed based on the Langmuir and–Brunauer–Emmett Teller (Brunauer-Emmett-Teller) adsorption theories. At low relative humidity, water molecules monomolecularly bind to hydrophilic groups in the fibroin chain, whereas with increasing humidity, multilayer adsorption and capillary condensation processes occur in the intermicrofibril spaces. This is the main hygienic factor that provides silk with a high hygroscopic index (11-12%), distinguishing it from cotton (7-8%) and other natural fibers. Mechanically, the β -sheet structure formed by the amino acids glycine (42-45%) and alanine (28-32%) in fibroin guarantees a high degree of crystallinity (40-50%) and strength of the fiber up to 0.4-0.6 GPa. Chemical analyses have shown that silk is stable in acidic environments, but protein chains are broken down under the influence of strong alkaline conditions. In general, the unique physicochemical properties of silk fibers make them a competitive raw material not only in traditional textiles but also in the creation of high-tech and biocompatible materials.

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STUDYING THE RELATIONSHIP BETWEEN HERBAL COMPOUNDS AND FOOD SAFETY

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https://doi.org/10.5281/zenodo.20034864

Abstract. *This article examines the relationship between herbal compounds and food safety, with particular attention to the role of plant-based medicinal substances, microelements, and chemical contamination in human health. The study discusses how natural plant products can provide essential nutrients, vitamins, and biologically active compounds when consumed fresh, properly stored, and hygienically prepared. At the same time, it highlights major risks to food safety, including environmental pollution, roadside food sales, excessive use of chemical fertilizers and pesticides, animal waste contamination, artificial additives, preservatives, and long-term storage. The article emphasizes that unsafe agricultural and food production practices may reduce nutritional value and increase the presence of toxic substances in fruits, vegetables, meat, and dairy products. Based on the analysis, practical recommendations are proposed for improving food safety through natural production methods, sanitary control, proper storage, laboratory testing, and protection of agricultural areas from pollution and contamination.*

Keywords: *herbal compounds, food safety, medicinal plants, microelements, chemical contamination, food hygiene, agricultural products.*

INTRODUCTION

The most important products for human health are the medicinal substances contained in plants, which include a natural complex of microelements. Microelements are important for the survival of all living organisms, and their number in organs and tissues exceeds 70. The amount of microelements in organs that participate in the metabolic processes in the body is determined by the role they play. The most important products for human health are the medicinal substances contained in plants, which include a natural complex of microelements. Microelements are important for the survival of all living organisms, and their number in organs and tissues exceeds 70.

It should be said that ensuring the safety of food products is not only the task of medical workers, but also the duty of all of us. In this regard, studying the relationship between medicinal substances contained in plants and food safety and ensuring the safety of food products is becoming an increasingly urgent problem.

LITERATURE REVIEW

Plant-based food products are considered an important natural source of biologically active substances, including microelements, vitamins, carbohydrates, proteins, fats, organic acids, and medicinal compounds. These components play a significant role in maintaining human health, supporting metabolism, and strengthening the body’s resistance to harmful environmental influences. Microelements are especially important because they participate in many metabolic processes and contribute to the normal functioning of organs, tissues, and physiological systems [1]. However, their effect on the body depends not only on their presence in food products, but

also on their proper balance. Both deficiency and excessive accumulation of macro- and microelements may disturb biological processes and lead to various pathological conditions [1]. Therefore, the study of the chemical composition of plant products is closely connected with food safety, nutritional value, disease prevention, and public health protection.

The nutritional and medicinal value of plants is largely determined by the natural preservation of their chemical composition. Fruits, vegetables, herbs, legumes, and medicinal plants contain useful substances that are most beneficial when consumed fresh, naturally ripened, and minimally processed [2]. In their natural state, plant products retain proteins, fats, carbohydrates, vitamins, and microelements more effectively. However, improper storage conditions, including excessive heat, cold, dryness, and humidity, may negatively influence their biological composition and reduce their nutritional quality [2–3]. For this reason, the correct harvesting period and appropriate storage conditions are important factors in maintaining the safety and usefulness of plant-based foods. For example, grapes consumed before full ripening contain lower amounts of sugar and higher levels of acidic compounds, while grapes harvested too late may lose part of their vitamins, minerals, and natural nutrients [2–3].

Previous studies also show that different plant products have different levels of resistance to storage and environmental influence. Among perishable fruits, vegetables, and melons, legumes are relatively more stable and can be stored for longer periods without serious loss of quality [2]. Naturally dried fruits are also valuable because their useful composition is largely preserved when drying is carried out under proper conditions. For instance, raisins produced from grapes dried in the sun or shade retain carbohydrates, microelements, and vitamins, which explains their nutritional and medicinal importance [2–3]. This indicates that traditional and natural preservation methods may help maintain the biological value of food products without excessive dependence on artificial additives or chemical preservation.

At the same time, food safety is affected not only by the internal composition of plant products, but also by external environmental and hygienic factors. The quality of fruits, vegetables, greens, and melons may deteriorate as a result of pollution, poor storage, animal waste contamination, and non-compliance with sanitary rules [3]. In rural areas, where many plant products are grown in household gardens, contamination by domestic animals can create serious health risks. In particular, the free movement of dogs and other animals, lack of veterinary control, and contact of urine or feces with vegetables, greens, and water sources may increase the spread of infectious and parasitic diseases, including helminthiasis and echinococcosis [3]. Thus, food safety should be understood not only as the absence of chemical contamination, but also as the protection of food products from biological, environmental, and hygienic risks.

Overall, the reviewed literature suggests that the relationship between herbal compounds and food safety is multidimensional. Plant products are valuable because they contain natural medicinal substances and essential microelements, but their usefulness depends on proper cultivation, ripening, storage, drying, and hygienic handling [1–3]. Therefore, ensuring food safety requires an integrated approach that combines chemical composition analysis, preservation of natural nutritional value, prevention of contamination, and strict observance of sanitary standards. This approach is especially important in protecting public health and improving the quality of daily food consumption.

METHODOLOGY

This study was conducted through a descriptive and analytical review of scientific sources and practical observations related to herbal compounds, microelements, storage conditions, and

food safety risks. The analysis focused on the nutritional and medicinal value of plant products, particularly fruits, vegetables, greens, melons, legumes, and naturally dried fruits. Special attention was given to how storage, ripening level, drying methods, environmental exposure, and hygienic conditions influence the biological composition and safety of food products. Legumes were considered relatively stable among perishable agricultural products because they can be stored for a longer period with less quality loss. Naturally dried fruits, including raisins, were also analyzed as products that may preserve carbohydrates, microelements, and vitamins. In addition, the study examined potential contamination risks in rural households and agricultural areas, especially the contamination of vegetables, greens, and water sources by animal waste. Such factors were evaluated as possible causes of infectious and parasitic diseases, including helminthiasis and echinococcosis, when sanitary and veterinary control is not properly maintained.

RESULTS

Exhaust gases and toxic substances from manufacturing plants and vehicles harm food products through the external environment. Eating in canteens located near major roads and purchasing daily consumer products from roadside shops cannot be without harmful effects on human health. For example, gas and dust from meat trucks sold near busy roads can be inhaled. It should be noted that the smoke from cars contains the chemical element lead (tetraethylene lead), which has a very harmful effect on humans, and it is absorbed into all food products sold near the road. Such gases and fumes have the property of spreading up to a distance of 50 meters. From a hygienic point of view, it is impossible to allow food products to be sold near the road. A person can be poisoned by lead without knowing it. As a result, (lead) anemia develops and is very difficult to treat. Chemical fertilizers, herbicides, insecticides and other chemicals used in the cultivation of plant products remain in fruits, vegetables and greens for a long time and enter the human body directly or through animal products.

In order to meet the population's demand for food, in recent years, animals have been fed with artificial nutrients, antibiotics and hormones, which have caused a number of medical and hygienic problems, which, in turn, are detrimental to the health of the population, as is well known to those working in this field.

The addition of synthetic vitamins, preservatives, coloring and flavoring products to natural nutrients in food production sources can harm the health of people, especially mothers and children.

At a time when the soil and water contain low levels of minerals essential for plants and humans - sodium, potassium, iodine, selenium, iron, copper, zinc, chromium and other minerals - re-cultivation of the land two or three times a year in order to obtain high yields, and their excessive use leads to a further depletion of these important microelements in the soil.

When the necessary minerals are lacking in the soil, water and air, they are naturally also scarce in plant products and in the animals that consume them. By increasing the fertility of the soil and using chemicals against various insects and diseases, productivity increases, their shelf life is extended, and the appearance of fruits, vegetables and grains supposedly improves. However, the most essential nutritional value is constantly decreasing.

Chemicals used in agriculture can be considered a "mine" that acts slowly and is buried in the ground. They accumulate in the soil as a result of repeated and repeated use for decades, and even settle in plants, water sources, and then in animal tissues, negatively affecting the health of living organisms. Toxic substances that enter the animal body from the environment enter our bodies through the milk and meat products we consume. They cause disorders (diseases) that

develop one after another in the core of human organs. As a result, various diseases develop. Sometimes they can cause premature aging and premature death.

As a result of long-term storage of food products, the vitamins, minerals and nutrients they contain gradually lose their beneficial value. For example, it has been found that after the expiration date of potatoes, only more than 8 percent of the necessary substances in them are preserved.

Chemical food additives, such as preservatives, artificial colors and flavors, are mainly used to enhance the taste of food, enhance its quality, slow down spoilage, and increase its shelf life. The addition of these substances in excess amounts has a carcinogenic effect and is often considered a cause of cancer.

DISCUSSION

All this indicates how dangerous the food products we consume without knowing it are. Recent studies in some countries show that in most food products, along with a deficiency of microelements necessary for human life, the amount of elements with toxic effects is increasing above the norm. This, in turn, naturally creates a number of difficulties in ensuring the safety of agricultural products. In particular, it is becoming increasingly difficult to ensure the safety of melons, onions, tomatoes, potatoes and other types of food products consumed daily. Since such products are purchased directly from the market or grown on the farm, the ability to control their safety is limited. However, there are also products that are free from chemicals, such as apricots, mulberries, walnuts, almonds, pistachios, pears, hawthorn, pomegranates, peaches, cherries and cherries, which are very beneficial for human health. Although chemicals are practically not used in such products, it is difficult to call them completely environmentally friendly products, since fruit trees and other agricultural products grown in areas near cities and industrial centers can become unusable due to air pollution.

CONCLUSION

Based on the scientific analysis, it can be concluded that food safety is closely connected with the quality of raw materials, environmental cleanliness, hygienic handling, storage conditions, and the level of chemical exposure during production [1, 4]. Plant-based and animal-based food products may lose their nutritional value or become harmful when they are grown near polluted areas, stored for too long, treated with excessive chemicals, or sold in unhygienic conditions [2, 4]. Therefore, food safety should not be understood only as the absence of visible spoilage, but also as the prevention of hidden chemical, biological, and environmental risks [3, 5]. To protect public health, it is necessary to promote natural production methods, strengthen sanitary control, prevent roadside food sales, require laboratory testing, and ensure proper storage and shelf-life monitoring [1–5].

№	Main recommendation	Practical meaning
1	Consume natural and pure food products	Fresh, minimally processed foods help preserve nutritional and medicinal value.
2	Use biological production methods	Natural methods should be preferred instead of chemicals that may change food composition.
3	Keep crops away from highways	Fruits, vegetables, and melons should be grown at least 50 meters away from roads to reduce pollution exposure.

№	Main recommendation	Practical meaning
4	Avoid cultivation near chemical plants	Food products should not be grown close to industrial or chemical production areas.
5	Prevent open roadside food sales	Bread, meat, fruits, vegetables, and other foods should not be sold openly near roads.
6	Locate catering facilities safely	Public catering establishments should be placed at least 50 meters away from major roads.
7	Require laboratory testing	Food products sold in markets should pass safety testing, and consumers should be informed about the results.
8	Follow hygiene rules	Food products, especially chemically treated fruits and vegetables, should be washed and cleaned carefully.
9	Protect agricultural areas	Food-growing areas should be fenced to prevent contamination by domestic and wild animals.
10	Control product shelf life	Grocery stores should strictly follow expiration dates and organize regular quality control.

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SYNTHESIS AND QUANTUM-CHEMICAL ANALYSIS OF A COMPLEX COMPOUND OF Cu(II) ION WITH INDOLE-3-ACETIC ACID AND ACETAMIDE

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https://doi.org/10.5281/zenodo.20035267

Abstract*. This article presents the results of the synthesis and quantum-chemical analysis of a new mixed-ligand coordination compound based on the divalent copper (II) ion with indole-3-acetic acid (IAA) and acetamide (AA) ligands. The aim of the study is to determine the conditions for the formation of the complex compound and to investigate its composition, structure, and electronic properties using modern physicochemical methods. Elemental analysis of the synthesized complex confirmed its stoichiometric composition, while IR spectroscopy revealed the coordination modes of the ligands to the metal ion. In particular, it was established that indole-3-acetic acid participates in coordination through the carboxylate group, whereas acetamide coordinates via the carbonyl oxygen atom. In the theoretical part of the study, the geometric structure of the complex was optimized using Density Functional Theory (DFT), and its stability was evaluated. Quantum-chemical calculations were performed to determine the Mulliken charge distribution of atoms in the molecule, the energies of the HOMO and LUMO orbitals, and the energy gap (ΔE). The obtained results indicate the high stability and reactivity of the complex compound.*

Furthermore, these parameters are of significant importance for predicting the plant growth-stimulating properties of the complex. The results of this study can be applied in the fields of coordination chemistry, bioinorganic chemistry, and the development of new agricultural stimulants.

Keywords: *copper(II) complex, indole-3-acetic acid, acetamide, coordination compounds, synthesis, IR spectroscopy, DFT calculations, HOMO-LUMO, biological activity.*

INTRODUCTION

One of the promising areas of modern coordination chemistry is the synthesis and fundamental study of metal complexes containing biologically active ligands. In particular, coordination compounds of 3d-metals, especially the copper (II) ion, formed with various organic compounds, are distinguished by their unique physicochemical and biological properties. Copper is considered a vital trace element and directly participates in numerous enzymatic processes in living organisms and the metabolic systems of plants. In this study, indole-3-acetic acid (IAA), chosen as a ligand, belongs to the auxin family—a natural hormone that plays a crucial role in plant physiology. IAA regulates the processes of plant cell elongation, division, and rooting. However, auxins in their pure form can be unstable against environmental factors. Converting them into coordination compounds with metal ions not only increases the stability of the substance

but also significantly enhances its biological efficacy, which is being confirmed in scientific research. The use of acetamide as a second ligand serves to enrich the coordination sphere of the complex and improve the solubility properties of the molecule. Currently, enriching experimental results with theoretical analysis is one of the key factors determining the quality of scientific articles. Therefore, along with the structural descriptions of the synthesized complex, the article presents results obtained using modern quantum-chemical calculation methods, specifically Density Functional Theory (DFT). DFT calculations allow for the prediction of geometric parameters of the molecule, distribution of electron density, and energetic stability. The relevance of this work is determined by identifying the relationship between the structure and properties of mixed-ligand copper (II) complexes and establishing the theoretical foundations for creating new types of highly effective stimulants that can be applied in agriculture. Modern chemical research is inconceivable without quantum-chemical analysis. The initially selected main ligand, indole-3-acetic acid (heteroauxin, IAA), and the newly synthesized coordination compound $[Cu(IAA)_2(AA)_2]\cdot 2H_2O$ were studied using the Gaussian program with the CAM-B3LYP basis set. The aim of this article is to synthesize a mixed-ligand complex compound of the Cu(II) ion with indole-3-acetic acid and acetamide, to confirm its composition using modern physicochemical methods, and to theoretically substantiate the stable structure and electronic properties of the complex through quantum-chemical calculations.

LITERATURE REVIEW

In recent years, the synthesis of 3d-metal complexes based on biologically active ligands has remained one of the most pressing areas of coordination chemistry. In particular, copper (II) ion compounds formed with organic acids and amides have attracted significant scholarly attention due to their bioactivity and potential applications in agriculture. Indole derivatives, specifically indole-3-acetic acid (IAA), are well-known plant hormones, and their coordination with metal ions has been studied for several decades. For instance, G. Micera et al. [2] investigated the complexes of IAA with copper (II) and other divalent metals, demonstrating that the ligand binds to the metal ion via the carboxylate group. Similarly, the work of P. Piu et al. [1] indicates that indole acids form stable complexes with metal ions, often resulting in a stoichiometric composition of $M(L)_2$.

In the realm of mixed-ligand complexes, the role of amides is indispensable. M.R. Ibragimova and co-authors [3] studied mixed-ligand complexes of copper (II) nicotinate with acid amides. Their research reveals that amides coordinate with the metal ion through the carbonyl oxygen, enhancing the solubility and thermal stability of the complex. Furthermore, A.M.N. Khaleel [5] synthesized complexes of IAA derivatives with copper, cobalt, and nickel ions, confirming their square-planar and octahedral structures.

Quantum chemical calculations are becoming increasingly important in bridging theoretical and experimental results. In their work, N. Omirzak and R.S. Yerkasov [4] performed a quantum chemical analysis of copper halide complexes with acetamide using the PM3 method. This study calculated the energy parameters, charge distribution, and stability of the molecule. Such calculations, particularly the Density Functional Theory (DFT) method, allow for the prediction of the electronic structure and potential biological activity of newly synthesized complexes. The synthesis of new complexes based on biologically active ligands—specifically plant growth hormones (auxins) and pharmaceuticals—is an extensively researched field in coordination chemistry. Indole-3-acetic acid (IAA), which plays a vital role in plant physiology, and its interaction with metal ions hold both fundamental and practical significance [10,11]. Research by L. Strinna Erre et al. [6] on the complexation of indole derivatives with copper (II)

ions shows that indole acids primarily coordinate with the metal ion via the carboxylate group. Their work proved that whether copper (II) complexes adopt mononuclear or dimeric (polynuclear) structures depends on the nature of the substituents within the ligand.

Additionally, Duygu İnci and co-authors [8] investigated ternary complexes formed by copper (II) ions with IAA and aromatic planar ligands (e.g., 1,10-phenanthroline). Their findings indicated that such complexes serve not only as plant growth stimulators but also possess strong antioxidant properties and DNA-binding capabilities. The role of the amide group in mixed-ligand complexes also warrants special attention. Karim Chkirate et al. [9] studied the synthesis and crystal structure of pyrazole-acetamide based copper (II) complexes. The study showed that the amide group ensures the supramolecular structure and stability of the complex by forming a hydrogen-bonding network. Furthermore, G.G. Nnabuike et al. [7] examined copper (II) complexes with non-steroidal anti-inflammatory drugs (indomethacin), finding that N-donor ligands within these complexes can alter the coordination environment around the metal and enhance biological efficacy. Currently, integrating experimental results with theoretical analysis is an essential part of scientific research. Literature data indicates that studying the electronic structure, HOMO and LUMO orbitals, and the stability of copper (II) complexes using the DFT method enables the prediction of the complex's reactivity and biological activity.

In conclusion, the literature review demonstrates that a comprehensive study of mixed-ligand complexes of the copper (II) ion with IAA and acetamide—through both synthetic methods and modern DFT techniques—will contribute to obtaining new scientific insights in this field.

RESEARCH METHODOLOGY

The mixed-ligand coordination compound of cuprum(II) chloride with indole-3-acetic acid and acetamide was synthesized using the following procedure. First, 0.01 mol (1.75 g) of indole-3-acetic acid (IAA) was dissolved in 50 mL of ethanol. To ensure deprotonation of the ligand’s carboxyl group, 0.01 mol of potassium hydroxide (KOH) was added to the resulting solution. In a separate beaker, 0.005 mol (0.855 g) of cuprum(II) chloride dihydrate ($CuCl_2 \cdot 2H_2O$) was completely dissolved in 20 mL of distilled water. The metal salt solution was then added dropwise to the indole-3-acetic acid solution under constant stirring and mixed on a magnetic stirrer for 25–30 minutes. Afterwards, in order to form the mixed-ligand complex, a solution of 0.01 mol (0.59 g) of acetamide (AA) was added dropwise (5–10 mL) to the reaction mixture, followed by further stirring for 25–30 minutes. The reaction mixture was then continuously stirred at 50–55 °C for 1–1.5 hours using a magnetic stirrer [12]. At the end of the reaction, a clear, colorless solution was obtained. The resulting solution was purified by filtration, washed several times with a mixture of distilled water and ethanol, and dried in a vacuum desiccator (over P_2O_5) until constant mass was achieved [13,14]. As a result of the synthesis process, a clear colorless crystalline powder was obtained. The overall yield of the synthesis reaction was 82%, which confirms the high efficiency of the selected synthetic method. Based on the compositional analysis of the complex compound, it can be represented by the formula $[Cu(IAA)_2(AA)_2] \cdot 2H_2O$ [15]. The reaction equation can be expressed as follows.

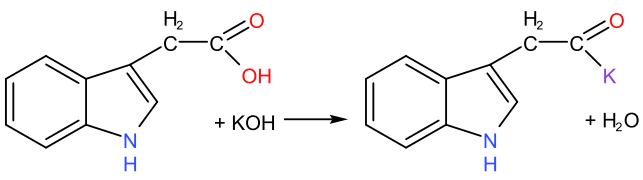


Figure 1. The reaction for obtaining the potassium salt of indole-3-acetic acid

In solution, the selected ligands lose their protons and are converted into IAA^- and AA^- anions. The Zn^{2+} ion possesses vacant coordination orbitals and forms coordination bonds with the IAA^- and AA^- ligands through the oxygen atoms of the carboxylate groups. **M = Cu.**

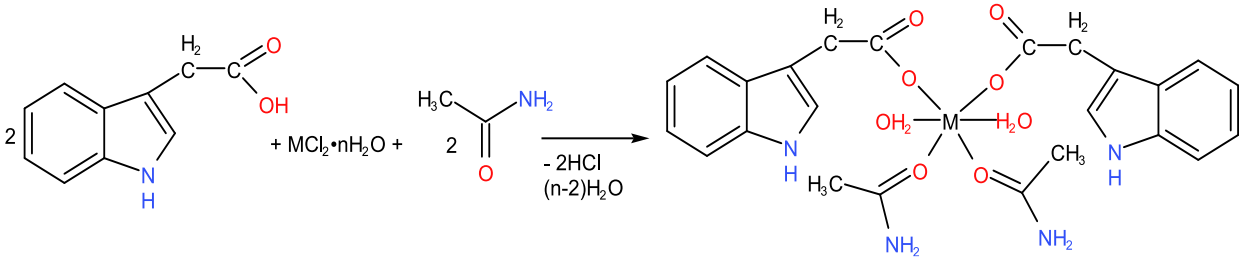


Figure 2. The reaction equation for the formation of the complex compound $[Cu(IAA)_2(AA)_2]\cdot 2H_2O$

As a result, a coordination compound with six coordination and octahedral geometry is formed. During crystallization, the resulting complex incorporates two water molecules, which are considered water of crystallization: $[Cu(IAA)_2(AA)_2]\cdot 2H_2O$.

ANALYSIS AND RESULTS

In this study, the electronic structure, geometric parameters, and stability of the synthesized complex $[Cu(IAA)_2(AA)_2]\cdot 2H_2O$ were investigated using quantum chemical calculations. All computations were carried out using the Gaussian program package. The geometry optimization and subsequent analyses were performed within the framework of Density Functional Theory (DFT) employing the range-separated hybrid functional CAM-B3LYP, which is known for its improved description of long-range electron interactions and charge-transfer systems. The initial molecular structure of the complex was constructed based on experimental coordination assumptions, where Cu(II) is coordinated by two indole-3-acetate (IAA^-) and two acetate (AA^-) ligands through oxygen donor atoms. Full geometry optimization was performed without any symmetry constraints, and the nature of the stationary points was confirmed by vibrational frequency analysis, ensuring the absence of imaginary frequencies.

The optimized structure reveals that the Cu(II) center adopts a distorted octahedral coordination environment, where the ligand molecules form stable coordination bonds via carboxylate oxygen atoms. The presence of crystallization water molecules plays an important role in stabilizing the supramolecular structure through hydrogen bonding interactions. Furthermore, frontier molecular orbital (FMO) analysis was carried out to evaluate the electronic properties of the complex. The energies and spatial distributions of HOMO and LUMO orbitals provide insight into the chemical reactivity, kinetic stability, and possible charge-transfer pathways within the complex [16]. The HOMO–LUMO energy gap indicates the relative stability of the system and its potential reactivity. Additionally, charge distribution analysis and electron density mapping were used to better understand the coordination behavior and electron delocalization within the complex system. These results provide a theoretical basis for interpreting the stability and physicochemical properties of the synthesized cuprum complex.

Similar to above complex, Cu(II) complex was optimized at the same level of theory and shown in Figure 3. The converged unrestricted wave function yielded a spin expectation value of $\langle S^2 \rangle = 0.7516$ before annihilation and 0.7500 after, confirming negligible spin contamination and a clean doublet ground state consistent with a d^9 Cu(II) center bearing one unpaired electron.

Natural bond orbital (NBO) analysis was carried out on the converged density to obtain atomic charges, natural electron configurations quantifying the strength of ligand-to-metal electron donation.

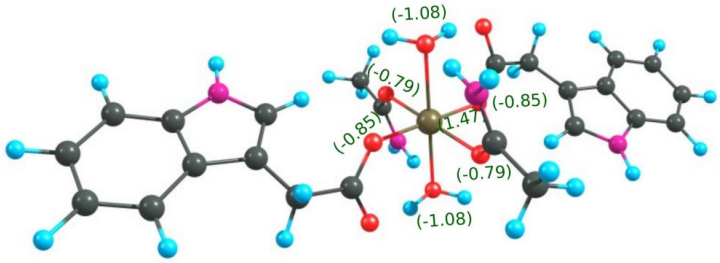


Figure 3. Optimized geometry of the Cu(II) complex (CAM-B3LYP/LANL2DZ) with NBO partial charges (green, in parentheses). Cu (gold), O (red), N (magenta), C (dark gray), H (cyan).

The NBO charge on copper was determined to be +1.47 e, substantially below the formal oxidation state of +2, similar results were observed by JV Burda et,al[1]. This reduction of 0.53 e from the ionic limit is directly reflects the greater covalent character of the Cu–O bonds arising from the more diffuse, partially filled d-shell of Cu(II). The natural electron configuration of copper is [core] 4s(0.26) 3d(9.24) 5p(0.02), confirming that the formal d^9 count is preserved in the NBO picture with the d-manifold holding 9.24 electrons in total. The six coordinating oxygen atoms fall into three chemically distinct groups, each with a characteristic NBO charge reflecting both their intrinsic donor ability and the extent of charge transferred to Cu(II). The indole-2-carboxylic acid oxygens that coordinate directly to copper carry charges of −0.853 e each, the most negative values among the directly bonded donor set. The non-coordinating partner oxygens of each carboxylate group bear significantly less negative charges of −0.743 e, confirming asymmetric bonding within the carboxylate unit in which one oxygen engages the metal while the other retains greater electron density. The acetamide carbonyl oxygens, which chelate copper through amide resonance-modulated lone pairs, carry charges of −0.792 and −0.791 e respectively. The terminal aqua oxygens bear the highest negative charges in the coordination sphere (−1.086 e each), which as in the Zn complex arises from O–H bond polarity rather than strong donation to the metal.

Moreover, the individual 3d orbital occupancies extracted from the NAO analysis provide a detailed picture of the d^9 electron hole distribution. The five d-orbitals are unequally populated, with $d_{x^2-y^2}$ (occupancy 1.591) and d_{xy} (occupancy 1.701) carrying the largest electron deficiencies. The dχz (1.991), d_{yz} (1.997), and d_{z^2} (1.961) orbitals remain nearly fully occupied. This pattern of preferential depopulation of $d_{x^2-y^2}$ and d_{xy} is the hallmark of a Jahn-Teller active Cu(II) center in an elongated octahedral or square-based coordination environment, where the equatorial ligand field splits the eg manifold and destabilizes the orbital pointing directly toward the strongest equatorial donors. The SOMO is thus predominantly $d_{x^2-y^2}$ in character with a secondary d_{xy} contribution, consistent with the complex's pseudo-square-planar equatorial plane defined by the four strongly donating indole-2-carboxylic acid and acetamide oxygens.

The fontier molecular orbital analysis HOMO-LUMO gap is 5.53 eV as shown in Figure 4. The partially filled d-shell of Cu(II) introduces a low-lying metal-centered acceptor state that pulls the LUMO energy down into the gap, compressing E_g considerably. This directly reflects the open-shell d^9 electronic structure of the Cu center. The LUMO is metal-centered, concentrated at the Cu–O coordination core and displaying orbital lobes with clear Cu d-character interacting with

the surrounding donor oxygen atoms. This confirms that the lowest-energy electronic excitation is a ligand-to-metal charge transfer (LMCT) process, in which electron density flows from the oxygen lone pairs and ligand π-system into the vacant d-based acceptor orbital on Cu[2]. This LMCT character is characteristic of open-shell Cu(II) and is consistent with the partial radical character already identified on the coordinating carboxylate oxygens through spin density analysis. The HOMO is ligand-centered, delocalized as a π-type bonding orbital across both indole aromatic ring systems on the two ligands simultaneously. The symmetrical HOMO topology across both ligands confirms equivalent electronic environments on the two indole fragments and suggests that photoexcitation can be used to probe the ligand π-framework through LMCT transitions. The chemical hardness $\eta = E_g/2 = 2.77$ eV classifies this complex as moderately hard. Research on the Mixed Ligand Cu(II) and Zn(II) Complexes by Mamaru Bitew Alem et, al.[3] shows similar character.

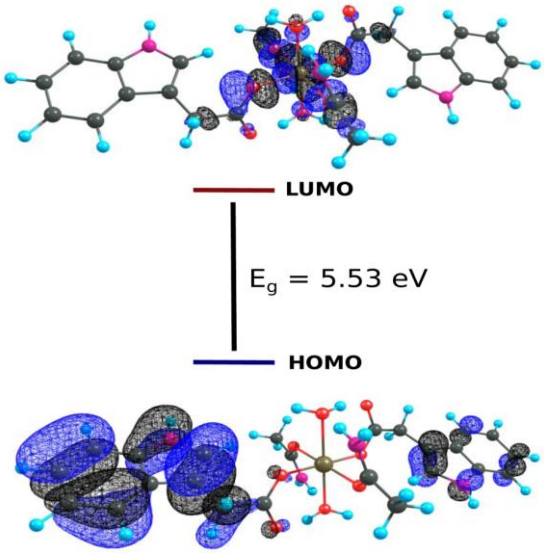


Figure 4. Frontier molecular orbitals of the Cu(II) complex (CAM-B3LYP/LANL2DZ, isovalue = 0.02 a.u.). Top: LUMO, localized on the Cu–O coordination core with significant metal d-character. Bottom: HOMO, delocalized across both indole ligand π-systems. E_g = 5.53 eV. Blue surface: positive phase; black mesh: negative phase.

The ESP surface (Figure 5.) shows a deep red nucleophilic zone at the Cu–O coordination core, broader and more intense than in the Ni(II) or Zn(II) analogues, consistent with the higher covalency (0.53 e charge transfer). Blue regions are localized symmetrically at the acetamide N–H protons on both ligands, marking them as the primary hydrogen-bond donor sites. The aromatic ring faces display near-neutral green/cyan π-electron density.

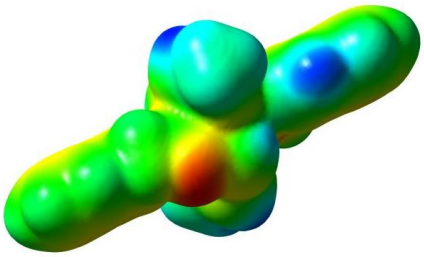


Figure 5. Electrostatic potential (ESP) surface of the Cu(II) complex mapped on the 0.001 a.u. electron density isosurface (CAM-B3LYP/LANL2DZ). Red: most electron-rich (negative potential, Cu–O coordination core); blue: most electron-poor (positive, amide N–H protons);

green/cyan: near-neutral aromatic π-faces; yellow: mildly electrophilic C–H periphery. The two elongated indole-containing arms extend horizontally.

CONCLUSION

The study successfully synthesized a new mixed-ligand coordination compound of Cu(II) with indole-3-acetic acid and acetamide, represented by the formula $[Cu(IAA)_2(AA)_2]\cdot 2H_2O$. The synthesis method produced a clear crystalline product with a high yield, confirming the effectiveness of the selected experimental procedure. The results of the structural and quantum-chemical analyses showed that the Cu(II) center forms a distorted octahedral coordination environment through oxygen donor atoms of the ligands.

The DFT calculations confirmed the stability of the synthesized complex and provided important information about its electronic structure, charge distribution, and frontier molecular orbitals. The HOMO–LUMO energy gap, NBO charge analysis, and electrostatic potential surface demonstrated the moderate hardness, covalent character of Cu–O bonds, and possible charge-transfer activity of the complex. These findings indicate that the synthesized compound may possess promising biological and plant growth-stimulating properties. Overall, the results contribute to the development of coordination chemistry, bioinorganic chemistry, and the design of new metal-based agricultural stimulants.

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SYNTHESIS OF HYDROGENATION CATALYSTS FOR HYDROPROCESSING OF PETROLEUM FRACTIONS

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https://doi.org/10.5281/zenodo.20048348

Abstract. *This article examines the synthesis of hydrogenation catalysts for the hydroprocessing of petroleum fractions using non-traditional support components, particularly spent alumina adsorbent and kaolin clay. The study focuses on the possibility of partially replacing imported aluminum hydroxide with locally available raw materials while maintaining the required catalytic activity, mechanical strength, and porous structure. Catalyst supports were prepared by extrusion, peptization with nitric acid solution, and heat treatment in air or nitrogen. Their physicochemical properties were studied using porosimetry, electron microscopy, X-ray diffraction, thermal analysis, infrared spectroscopy, atomic absorption spectroscopy, and chromatography. The results show that the introduction of spent alumina adsorbent and kaolin improves the structural characteristics of the supports and provides stable hydrogenation performance. The developed catalysts demonstrated satisfactory activity in hydrodesulfurization and dearomatization processes. Industrial testing confirmed their suitability for producing base oils under refinery conditions.*

Keywords: *catalysts, activity, hydroprocess, aluminium, oxide, dearomatization, carbonization of carriers, spent adsorbent.*

Introduction

It is well recognized that **t**he increasing demand for ultra-clean fuels, coupled with the growing share of heavy crude oils with high aromatic hydrocarbon content in the overall composition of produced and processed petroleum feedstocks, both in Uzbekistan and in many other countries worldwide, poses serious economic and technological challenges for the modern oil refining industry. In particular, the global market for middle distillates is steadily growing, while the quality of available feedstocks is significantly declining. Low-quality feedstocks or even alternative renewable feedstocks require processing to meet the demand for additional ultra-clean motor fuels. Therefore, the role of hydrocatalytic processes in oil refining is rapidly increasing.

This paper examines various aspects of the use of non-traditional support components for the synthesis of hydrodearomatization catalyst elements for the processing of petroleum fractions. Aluminum hydroxide (AH), the main component of the catalysts by weight, is not produced in the Republic of Uzbekistan. One of the raw material sources of aluminum oxide is the large-scale waste product of the Shurtan Gas Chemical Complex—spent alumina adsorbent (SAO). Therefore, we conducted a series of studies that demonstrated the feasibility of replacing up to 60% of imported aluminum hydroxide with SAO and kaolin clay from the Angren deposit (kaolin), which acts as a regulator of pore structure and strength.

Materials and Methods

It is instructive to note that catalyst supports were obtained by extrusion, peptizing a

mixture of starting material powders (Table 1) with an aqueous HNO3 solution, and heat treatment in air or nitrogen. The studies were conducted using the following instruments: a Carlo Erba mercury porosimeter, a JXA 8800R Super probe electron microanalyzer (Jeol), a Dron-3 diffractometer, a Q-1500 D derivatizer, a Tesla electron microscope, a Specord-75 IR spectrometer, an SP 9 PYE UNICAM atomic absorption spectrometer, and a Chrom-5 chromatograph.

The electron spectra of the catalysts and adsorbed acid-base indicators, used to evaluate the surface properties according to the method [5], were obtained on a Hitachi-330 spectrophotometer. The amount of chemisorbed O2 was determined by pulsed gas chromatography after preliminary reduction of the catalysts in H2 at 823 K. The hydrogenation catalysts (highlighted in bold) were obtained by double impregnation with similar solutions, with intermediate heat treatment. The hydrogenation performance of the samples was assessed based on changes in the polyaromatic compound content of the feedstock and catalysts obtained in a pilot flow unit with a catalyst loading of 150 ml. Hydroprocessing of the deasphalted residual oil fraction and crude kerosene was carried out at a hydrogen pressure of 4 MPa, and that of the diesel distillate at 5 MPa. The reactor temperature was maintained between 573 and 593 K.

Results and Discussion

The GOA used for the synthesis of the samples consisted of a mixture of boehmite and pseudoboehmite and had weak acidic sites on the surface with pKa from +3.8 to +6.1. OAA contained (%): (30-50) γ-Al2O3, (5-15) ά -Al2O3 and (40-60) boehmite with crystal sizes from 10 to 100 nm. The impurity content (%) varied within the range: Na2O (1.7 ÷ 2.0), Cl (0.3-0.8), CaO (0-0.5), TiO2 (0.3-0.5) and V2O5 (0.4-0.6). On the OAA surface, along with weak acidic sites, basic sites with pKa = up to +10.3 were found. Kaolin contains 45-70% kaolinite (d = 7.18-7.14; 4.46; 3.57 and 2.6-2.2 Å) and 20-30% quartz (d = 4.26; 3.34; 2.45-2-46; 1.81-182; 1.54-1.55 and 1.38-1.37 Å). The main impurities are: P2O5 (0.6-0.7), SO3 (0.3-0.5), K2O (0.9-1.1), CaO (0.3-0.7), FeO (0.1-2.7) and BaO (0.2- 0.4). The acidity of kaolin was in the pKa range of +1.5 to +3.8.

It is essential to highlight that the use of OAA has specific characteristics due to its role in polyethylene production. Fresh adsorbent is designed to purify the polymer solution of polymerization catalysts (VOClx, TiClx), in the form of chelate complexes with deactivators, and a mixture of associated substances, by chemisorption at a temperature of 533-583 K and high pressure. The total carbon content of the chemisorbed substances ranged from 1.5 to 4.5% of the OAA mass. We have found that when heating 100 g of OAA granules to 513 K in a reactor, desorption of water occurs at 4.3 g/100 g and unidentified organic substances at 0.6 g/100 g with absorption bands of -CH2, -CH3 groups (2930, 2873-2843) cm-1, as well as C=O, C-O-H, C-O, O-H (1720, 1410, 1282, 933) cm-1) in the IR spectra of the gas phase. The evolution of CO and CO2 began above 520 K, reached a maximum concentration at 833-923 K, and was complete within 18 hours at 973 K. A total of 5.9 g CO, 4.8 g CO2, 1.6 g HCl, and 0.2 g H2O were released from 100 g of OAA in the 833-973 K zone.

The weight loss (Δ P) from H2O removal from fresh adsorbent in the endothermic zone at 393-453 K was less than 2%, and with complete conversion of boehmite to Al2O3, it was 7.2%. (Fig. 1, No. 1).

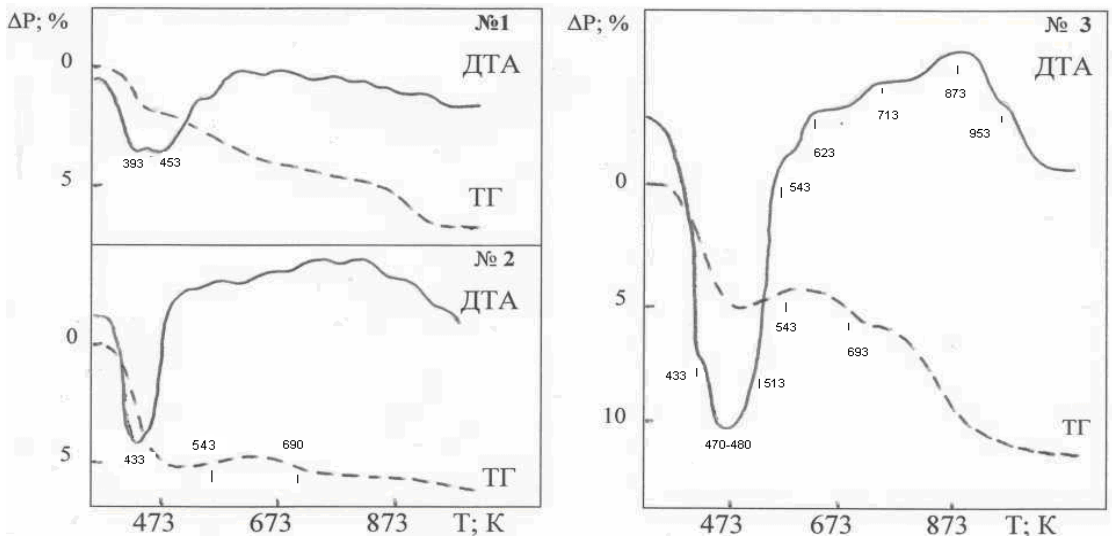


Fig. 1 Thermograms of fresh adsorbent - No. 1; OAA sample (1.5% C) - No. 2; OAA sample with the maximum content of chemisorbed substances (4.5% C) - No. 3.

It is relevant to note that under the conditions of thermogram recording (100 mg of OAA powder), an endothermic effect was observed with a weight loss (Δ P) of 5% and a minimum at 433-513 K, the depth of which was proportional to the carbon content. The weight increase of 1-2% in the exoeffect region of 543-693 K is explained by the addition of oxygen to chemisorbed substances, which prevails over the desorption of carbon gases and water. With a temperature increase of 10 degrees per minute, the weight change (Δ P = 7%) and thermal effects with the release of heat (543, 623, 713, 873, 953 K) CO, CO2, traces of water and HCl were observed for about an hour and ceased at 1093 K. The calculated weight loss during complete oxidation of compounds of the CH3(-CH2-) n-COOH type and chelate complexes of V and Ti, causing the presence of 0.6 mg V2O5, 0.5 mg TiO2 and 0.8 mg Cl in 100 mg OAA (Fig. 1, No. 3) is 7.2%. In this process, approximately 14 mg of O2 should be consumed, and 16.5 mg of CO2, 4.4 mg of H2O, and 0.3 mg of HCl should be released into the gas phase. Data from differential thermal analysis (DTA) and thermogravimetry (TG), combined with measurements of the amounts of H2O, CO, and CO2 formed during heating in air, indicate a stepwise removal of chemisorbed substances from the OAA with preliminary addition of oxygen and a high strength of chemical bonding with the adsorbent surface (Fig. 1, Nos. 2-3).

The mechanical strength and wide-pore structure of the dearomatization catalyst supports, due to the addition of OAA and kaolin, are maintained upon the application of active metals (Tables 1-2).

Table 1. Effect of composition and heat treatment conditions at 823-873 K on the specific surface area (Ssp.), carbon content (C), and surface properties of supports

Carrier Cipher	Composition of the carrier components (Carrier calcination medium)	$S_{sat.}$; m^2/g	C; %	pK_a surface centers (concentration; mg-eq/g)
№ 1	60% OAA+40% GOA (air)	160	0,05	- 5,6 (0,05); -3,3(0,15); +1,5(0,19); +3,8 (0,31); +9,3 (0,01)
№ 2	GOA+10% kaolin (air)	265	0	*-8.2(0.008); -5.6(0.08) -3.3(0.23); +1.5(0.34);*

№ 3	60%OAA+30% GOA +10% kaolin (air)	109	0,03	+1,5 (0,01); +3,8(0,18); +6,1(0,37); +9,3 (0,014)
№ 4	OAA+ 30% kaolin (air)	91	0	+1.5(0.13);+3.8(0.23); +6.1(0.25); +9.3(0.01)
№ 5	GOA (air)	275	0	-6.3(0.01); -5.6(0.07); -3.3 (0.24); +1.5(0.48); 3.8(0.50);

Table 2. Physicochemical characteristics of catalysts obtained on various supports

Cipher	Actual content of IPM; %						Carrier	Strength;	Pore radius; nm (Volume of the	Sud;
	Ti	V_2	W	Ni	C	Mo				
Kt -	**0**	**0**	**0**	**1.7**	**4.**	**17.9**	**№3**	**2.85**	**3-5(0.45); 5-15(0.060);**	**29**
Kt -	**0.**	**0.0**	**0**	**1.7**	**4.**	**17.6**	**№4**	**3.15**	**<3(0.12); 5-7(0.10);45-**	**10**
Kt -	**0.**	**0.0**	**0**	**6.0**	**0**	**18.1**	**№4**	**3.43**	**<3(0.10); 5-7(0.09);45-**	**10**
Kt -	**0.**	**0.0**	**1.4**	**5.9**	**0**	**17.8**	**№4**	**3.27**	**3-4(0.19); 10-**	**89**

It is appropriate to mention that with increasing concentrations of active components, the formation of very fine pores progresses during the thermal decomposition of hydrated nickel (cobalt) molybdates (tungstates), aggregated within the pores of the catalyst semi-finished product upon repeated impregnation with combined solutions. Based on the results of sequential extraction with water and an aqueous ammonia solution, it was shown that the proportion of Ni(Co) and Mo surface structures tightly bound to the support, responsible for hydrodesulfurization reactions, decreased to 30-60%, depending on the support [7]. The amount of weakly bound structures of Ni, Co, Mo and W (in the numerator), possessing the highest hydrogenating capacity, increased with the use of OAA and increased in the series (in the denominator, the sum of transition metals): Kt-6 (4.7 /24.7) < ≤ Kt-8 (11.5 /23.5) < Kt-9 (12.6 /24.2) ≤ Kt 10 (12.7/ 25.2). An increase in the relative intensity of the absorption bands from nickel and/or cobalt molybdates with octahedral cation coordination was observed. NiTd2+ and CoTd2+ ions in the composition of spinel structures, as well as NiWO4 in the composition of Kt-10, were not spectrally manifested (Fig. 2, curves 8, 9). Laboratory rig testing of comparative stability of catalysts obtained by impregnating carriers calcined in air and nitrogen during hydrotreating of the residual fraction boiling above 773 K revealed no trend toward progressive activity loss after 500 hours of testing and three experimental regenerations of catalysts on a carbonized carrier.

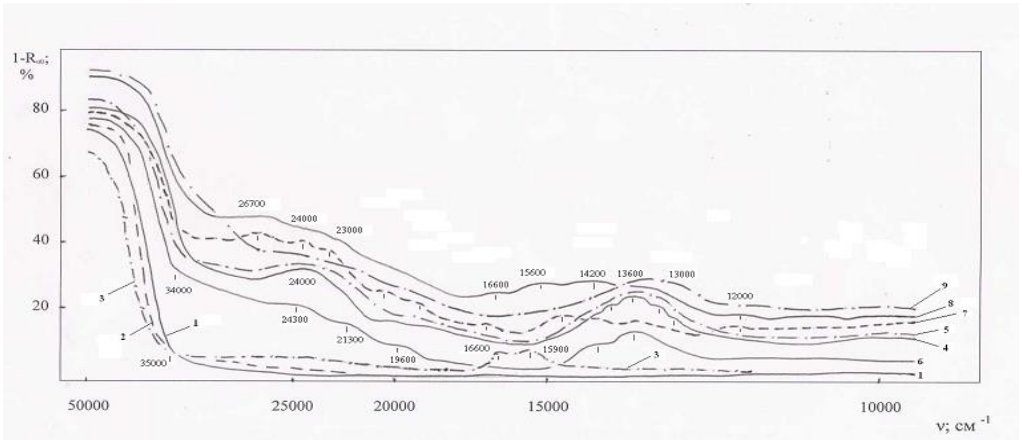


Fig. 2. Electronic spectra of catalysts: 1 - Kt-1; 2 - Kt-3*; 3 - Kt-17; 4 - Kt-14; 5 - Kt-16*; 6 - Kt-13*; 7 - Kt-7; 8 - Kt-8; 9 - Kt-10.

These developed scientific approaches have enabled the development and implementation of a number of catalysts using OAA and kaolin. Since 2012, a pilot run of a dearomatization

catalyst has been conducted at the Fergana Oil Refinery's G-24 unit as part of a multilayer catalytic system based on an industrial AKM catalyst. There has been no increase in pressure drop. The quality of the resulting base oils fully complies with the company's standards. Full-scale catalyst loading into the Fergana Oil Refinery reactors is planned for the future.

Conclusion

1. A combination of physicochemical methods has established that catalysts prepared using OAA and kaolin are comparable in activity and stability to aluminum hydroxide-based catalysts and can be recommended for use in industrial reactors.

2. Slightly more complex technology in producing a carrier with OAA allows for the production of catalysts with increased activity in removing sulfur compounds and impurity metals.

3. Positive results were obtained from pilot batches of the developed catalysts under industrial conditions on a G-24 unit during the production of base oils.

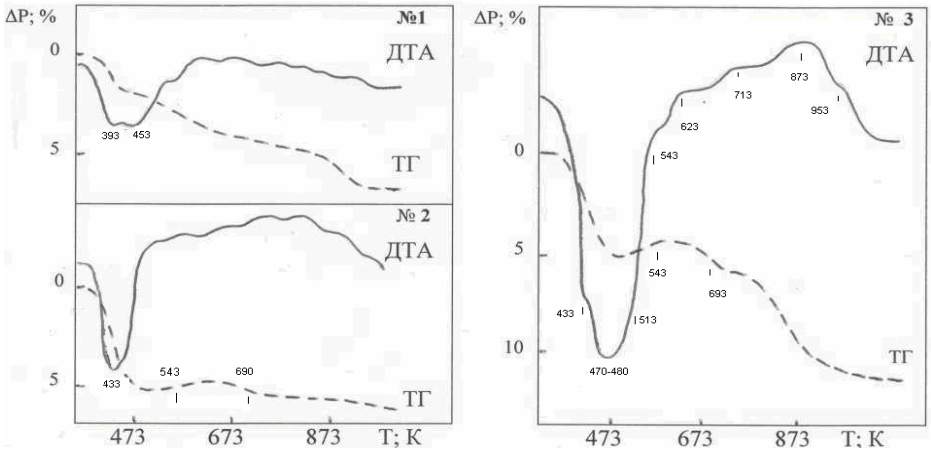


Fig. 1 Thermograms of fresh adsorbent - No. 1; OAA sample (1.5% C) - No. 2; OAA sample with the maximum content of chemisorbed substances (4.5% C) - No. 3.

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SYNTHESIS OF 6H(CHLORINE)-BENZOTHIAZOLIN-2-ONE(-THIONE) DERIVATIVES

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https://doi.org/10.5281/zenodo.20049127

Abstract. *In this work, benzothiazoline-2-thione obtained from the reaction of o-aminothiophenol with thiourea was subjected to acylation with p-methoxybenzoyl chloride in the presence of benzene at 80 °C for 2h. As a result, (4-methoxyphenyl)-2-thioxobenzo[d]thiazol-3(2H)-yl) methanone was successfully synthesized, and its reaction with hydrazine hydrate was subsequently investigated. Furthermore, a novel and previously unreported catalyst-free microwave-assisted method was developed for the high-yield synthesis of 2-substituted 6H(Cl)-1,3-benzothiazoles within a short reaction time. In this approach, o-aminothiophenol (or 6-chloro-o-aminothiophenol) was reacted with various aldehydes in a microwave reactor at 65 W, and the influence of reaction time on the synthesis process was systematically examined. It was observed that increasing the microwave irradiation time led to a significant improvement in product yields. Under optimized conditions, the reaction of o-aminothiophenol and aldehydes in a 1:1 molar ratio using an ethanol–water (1:1) solvent system afforded 2-substituted 6H-1,3-benzothiazoles in moderate to good yields within 3-4 minutes and in high yields after 5 minutes of irradiation. Similarly, the reaction of 6-chloro-o-aminothiophenol with aldehydes under the same molar ratio and solvent system in a microwave reactor resulted in moderate to good yields within 4-6 minutes and high yields within 7 minutes, leading to the efficient synthesis of 2-substituted 6(Cl)-1,3-benzothiazole derivatives.*

Keywords: *o-aminothiophenol, p-methoxybenzoyl chloride, 3-methoxybenzaldehyde, (4-methoxyphenyl)2-thioxobenzo[d]thiazol-3(2H)yl)methanone, -(4-chlorophenyl)-6(chlor)-benz othiazole.*

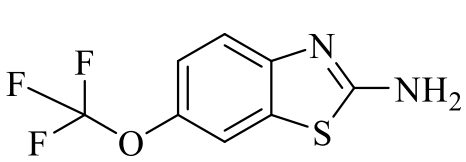
Introduction

According to the literature, numerous benzothiazole derivatives have been developed that exhibit a wide range of biological activities, including anticancer [1; 5424-5427 pp., 2**;** 7095-7103 pp.], antimicrobial [3; 1795-1801 pp., 4; 3681-3685 pp., 5; 5599-5608 pp.],, anti-inflammatory [6; 34-38 pp.], antitubercular [7; 137-145 pp., 8; 275-281 pp.], anti-HIV (acquired immunodeficiency syndrome) [9; 868-882 pp.], antimalarial [10; 995-998 pp.], anticonvulsant [11; 1345-1349 pp.], anthelmintic [12; 459-464 pp., 13; 439-442 pp.], antioxidant [14; 2228-2232 pp.], and bactericidal 15; 118-125 pp.] properties. In addition to their

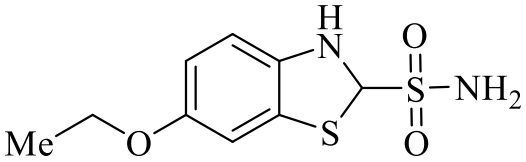
pharmaceutical applications, several benzothiazole-based compounds have been identified as fungicides [16–18], herbicides [19–21], and plant growth regulators [22–25].

In view of these findings, continued research aimed at the discovery of new biologically active substances has been undertaken, focusing on the investigation of inhibitory and growth-regulating activities of this class of compounds. Such studies are of considerable interest not only from a theoretical perspective but also from a practical standpoint, due to the broad applicability of benzothiazole derivatives in medicinal chemistry, agriculture, and related fields Benzothiazoles possessing high synthetic potential continue to be of considerable interest to chemists and biologists. These compounds are widely recognized as important heterocyclic scaffolds in modern organic synthesis and pharmaceutical chemistry.

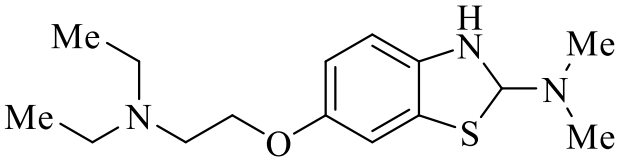
Below are the structural formulas of several clinically important drugs containing the benzothiazole ring system, including riluzole, ethoxzolamide, dimazole, Pittsburgh compound B, and flutemetamol, which further demonstrate the significant pharmacological relevance of this heterocyclic framework:



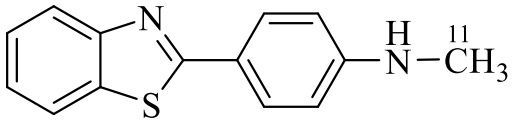
Riluzole



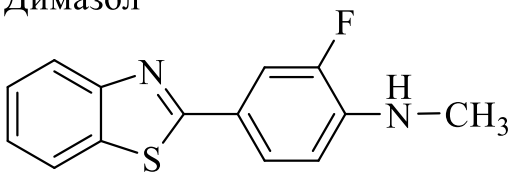
Ethoxzolamide



Димазол



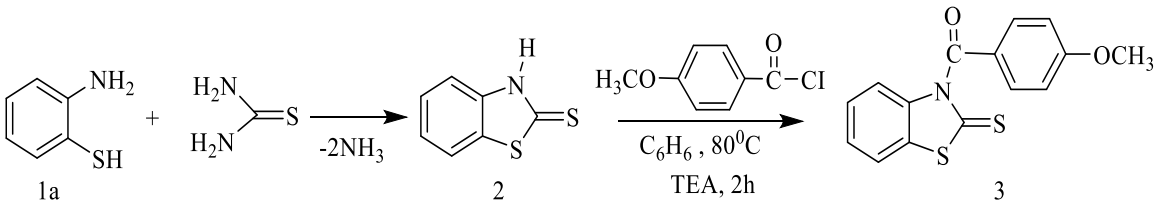
Pittsburgh compound B



Flutemetamol

Materials and Methods

Benzothiazoline-2-thione, synthesized via the reaction of *o*-aminothiophenol with thiourea, was reacted with *p*-methoxybenzoyl chloride in benzene in the presence of triethylamine as a catalyst. The reaction mixture was heated at 80 °C for 2 h. Upon completion of the reaction, the resulting precipitate was filtered and recrystallized from ethanol, affording *(4-methoxyphenyl)-2-thioxobenzo[d]thiazol-3(2H)-yl)methanone* (**3**) with an isolated yield of 80% (Appendices I and II).

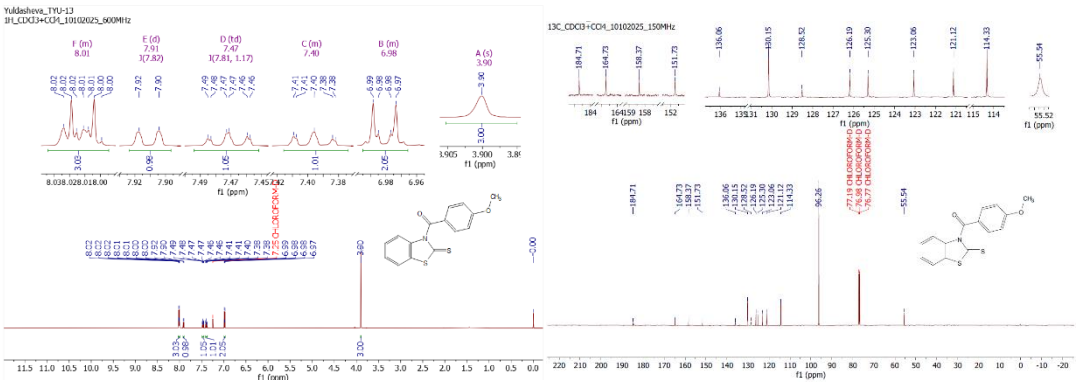


1a 2 3

Results

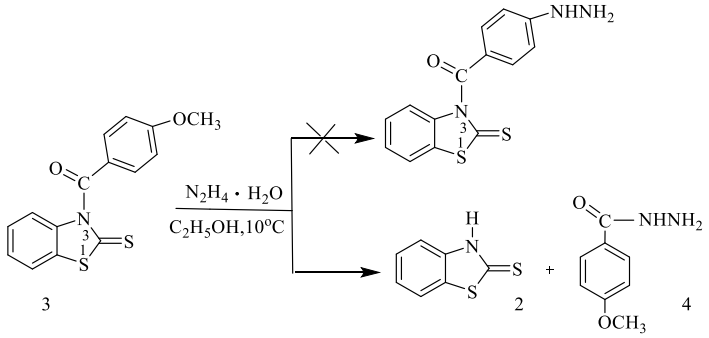
The structures of the synthesized compounds were confirmed by ^{1}H NMR, ^{13}C NMR, and X-ray crystallographic analysis.

Appendix I ***Appendix II***



^{1}H and ^{13}C NMR Spectral data of compound 3

The synthesized (4-methoxyphenyl)-2-thioxobenzo[d]thiazol-3(2H)-yl)methanone (**3)** was reacted with hydrazine hydrate in anhydrous ethanol at 10 °C. As a result of this reaction, the expected (4-hydrazinylphenyl)-2-thioxobenzo[d]thiazol-3(2H)-yl)methanone was not formed; instead, the formation of benzothiazoline-2-thione (**2**) and 4-methoxybenzohydrazide (**4**) was observed. The resulting compounds were separated by column chromatography using a petroleum ether–ethyl acetate (10:1) solvent system.



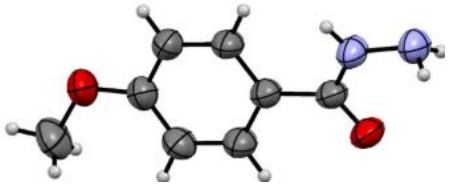


Figure I. X-ray crystal structure of compound 4

Discussion

It is well known that the reactions of *o*-aminothiophenol with certain aldehydes have previously been investigated in our earlier studies (**26**). Continuing these investigations, a novel method not previously reported in the literature was developed for the synthesis of 2-substituted 6(H)Cl-1,3-benzothiazoles via a catalyst-free microwave-assisted protocol, enabling high yields within a short reaction time. It should be emphasized that the reactions were carried out using two different approaches (Methods **A** and **B**). According to Method **A**, a 1:1 molar mixture of *o*-aminothiophenol (**1a**) and the corresponding aldehyde was stirred in an ethanol–water (1:1) solvent system at room temperature for 4 h, while the reaction of 6-chloro-*o*-aminothiophenol (**1b**) with aldehydes was conducted under heating for 6 h. Under these conditions, 2-substituted 6(H)Cl-1,3-benzothiazoles were obtained in high yields. In Method **B**, a 1:1 molar mixture of *o*-aminothiophenol (**1a**) and aldehyde in an ethanol–water (1:1) solvent system was subjected to microwave irradiation in a chemical microwave reactor at 85 °C and 65 W. Under these conditions,

moderate to good yields were achieved within 3–4 minutes, while high yields were obtained after 5 minutes, affording product (**4**).

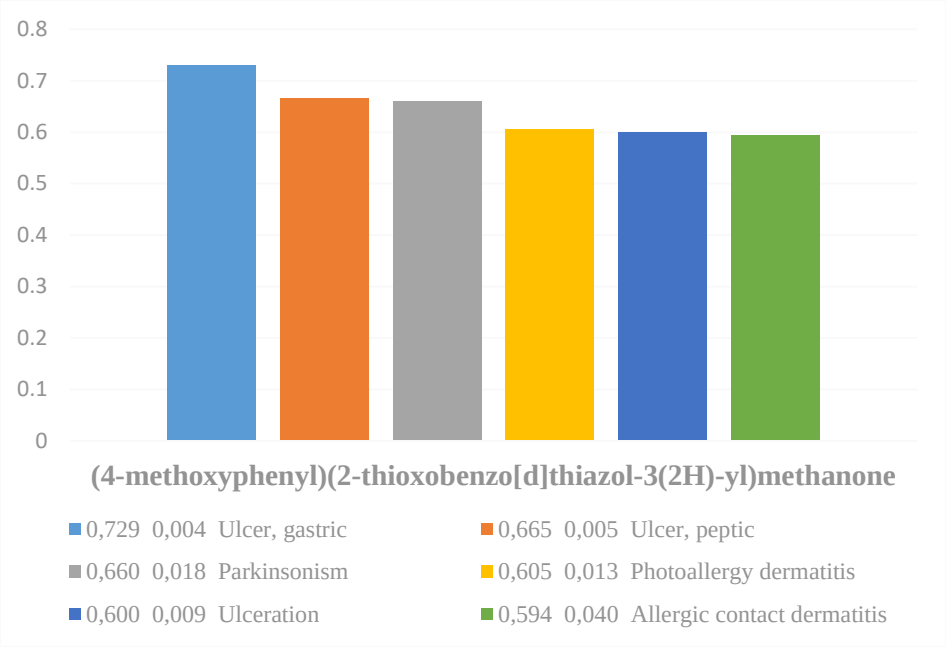
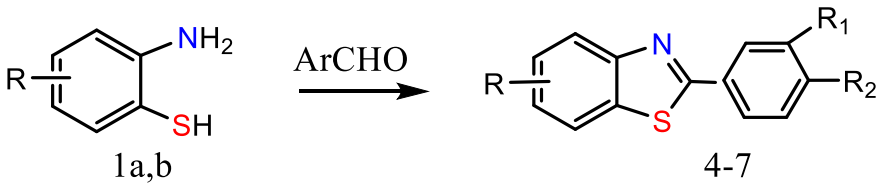


Figure II. Pharmacological activities of (4-hydrazinylphenyl)-2-thioxobenzo[d]thiazol-3(2H)-yl)-methanone predicted using the PASS (online) program.

Further microwave-assisted reactions were carried out using 6-chloro-*o*-aminothiophenol (**1b**) and aldehydes under identical conditions. In this case, moderate to good yields were achieved within 4–6 minutes, and high yields were obtained after 7 minutes, leading to the synthesis of products (**5–7**), as summarized in Table 1.



1a,b 4-7

R = H; CI R_1=OCH_3, R_2= H, CI

Table 1

№	Molecular formula	R_f	Melting point (^{0}C)	Reaction yield (%) after 4 and 6 hours	Reaction yield (%) MW, 5 and 7 min
4	$C_{13}H_{10}SN$	0.77	112-114	83,6	94
5	$C_{13}H_8SNCl$	0.75	104-106	80,6	85,5
6	$C_{14}H_{10}SNCIO$	0.54	74-76	79,7	83
7	$C_{13}H_7SNCI_2$	0.65	144-146	81	86,7

Conclusion

In conclusion, it was observed that the increase in reaction time leads to a corresponding increase in the yields of the synthesized compounds. Reactions carried out in a microwave reactor demonstrated high efficiency, providing excellent yields within short reaction times and without

the use of additional reagents or catalysts. Compared to conventional thermal methods, the microwave-assisted approach proved to be more effective and time-efficient.

Experimental Section

(4-Methoxyphenyl)-2-thioxobenzo[d]thiazol-3(2H)-yl)methanone (3)

A solution of benzothiazolin-2-thione (2.9 g, 17.4 mmol) in benzene (30 mL) was treated with *p*-methoxybenzoyl chloride (3.55 g, 20.8 mmol), followed by the addition of triethylamine (1.753 g). The reaction mixture was heated at 80 °C for 2 h. After completion of the reaction, the mixture was allowed to cool to room temperature, and the resulting precipitate was filtered. The crude product was recrystallized from ethanol to afford compound **3** as a white solid. Yield: 4.1 g (80%); Melting point: 164–166 °C; Rf = 0.50 (hexane : ethyl acetate 5 : 1).(Appendix I, II)

2-Phenyl-1,3-benzothiazole (4)

A solution of *o*-aminothiophenol (0.3125 g, 2.5 mmol) in an ethanol–water mixture (1:1, 25 mL) was treated with benzaldehyde (0.265 g, 2.5 mmol), and the resulting reaction mixture was irradiated in a microwave reactor for 5 min. After completion of the reaction, the mixture was cooled to room temperature, and the precipitate formed was filtered, washed with petroleum ether, and dried. The crude product was recrystallized from ethanol to afford compound **4** as an orange solid in 0.496 g yield (94%) with a melting point of 112–114 °C and Rf = 0.77 (A). ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 8.12 (d, J = 7.38 Hz, 1H, ArH), 8.02 (t, J = 7.42 Hz, 1H, ArH), 7.65 (t, J = 7.42 Hz, 1H, ArH), 7.33–7.39 (m, 3H, ArH), 7.19–7.25 (m, 3H, ArH); m/z = 212 ([M + H]+).

6-Chloro-2-phenyl-1,3-benzothiazole (5)

A solution of 6-chloro-*o*-aminothiophenol (0.40 g, 2.5 mmol) in an ethanol–water mixture (1:1, 25 mL) was treated with benzaldehyde (0.265 g, 2.5 mmol), and the resulting reaction mixture was irradiated in a microwave reactor for 7 min. Upon completion of the reaction, the mixture was cooled to room temperature, and the formed precipitate was filtered, washed with petroleum ether, and dried. The crude product was recrystallized from ethanol to afford compound **5** as a light orange solid in 0.525 g yield (85.5%) with a melting point of 104–106 °C and Rf = 0.75 (A).

^{1}H NMR (400 MHz, DMSO-d$_6$) δ 8.19 (d, J = 8.3 Hz, 1H, ArH), 8.13 (d, J = 2.12 Hz, 1H, ArH), 7.56 (dd, J = 7.61, 2.17 Hz, 2H, ArH), 7.36 (t, J = 7.61 Hz, 2H, ArH), 7.16 (m, 1H, ArH); m/z = 246 ([M + H]+). Molecular formula: $C_{13}H_8ClNS$.

6-Chloro-2-(3-methoxyphenyl)-1,3-benzothiazole (6)

The reaction was carried out following the same procedure as described above. A solution of 6-chloro-*o*-aminothiophenol (0.40 g, 2.5 mmol) in an ethanol **:** water mixture (1**:**1, 25 mL) was treated with 3-methoxybenzaldehyde (0.34 g, 2.5 mmol), and the reaction afforded compound **6**. in 0.57 g yield (83%) with a melting point of 74–76 °C and Rf = 0.54 (A). ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 7.99 (d, J = 2.5 Hz, 1H, ArH), 7.77 (d, J = 7.7 Hz, 1H, ArH), 7.60–7.70 (m, 2H, ArH), 7.32–7.50 (m, 2H, ArH), 7.16 (dd, J = 2.5, 7.8 Hz, 1H, ArH), 3.91 (s, 3H, OCH_3); m/z = 276 ([M + H]+).

6-Chloro-2-(4-chlorophenyl)-1,3-benzothiazole (7)

The reaction was conducted in a manner similar to the previous procedure. A solution of 6-chloro-o-aminothiophenol (0.40 g, 2.5 mmol) in an ethanol–water mixture (1**:**1, 25 mL) was treated with p-chlorobenzaldehyde (0.351 g, 2.5 mmol), and the reaction afforded compound 7 in 0.607 g yield (86.7%) with a melting point of 144–146 °C and Rf = 0.65 (A). ^{1}H NMR (400 MHz, DMSO-d$_6$) δ 8.17 (d, J = 7.9 Hz, 1H, ArH), 8.13 (d, J = 2.2 Hz, 1H, ArH),

7.56 (dt, J = 7.9, 2.2 Hz, 1H, ArH), 7.41 (d, J = 8.1 Hz, 2H, ArH), 7.32 (d, J = 8.1 Hz, 2H, ArH); m/z = 280 ([M + H]+). Molecular formula: $C_{13}H_7Cl_2NS$.

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ANALYSIS OF THE INFLUENCE OF THE COEFFICIENT OF FRICTION BETWEEN WHEEL AND PAVEMENT ON ASPHALT CONCRETE ROADS ON TRAFFIC SAFETY

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https://doi.org/10.5281/zenodo.19494051

Abstract. *This article examines the primary factor affecting traffic safety in the interaction between vehicle wheels and the road surface, which depends on weather conditions, the quality of the pavement material, and the composition of asphalt concrete. Standards are used to determine the coefficient of friction.*

Keywords: *automobile wheels, traffic safety, weather conditions, asphalt concrete composition, coefficient of friction, dry and wet conditions.*

Introduction

In our republic, large-scale measures are being implemented to increase the service life of highways, improve their operational indicators, and develop and implement new technologies that serve to increase the efficiency of repair processes established by current standards. The New Uzbekistan Development Strategy for 2022-2026 defines tasks, including "Improving road infrastructure and accelerating the development of the road network". Currently, global climate warming, in particular, the increase in air temperature in recent years, exacerbates the problem of plastic deformation of asphalt concrete pavements. Also, one of the urgent problems is the assessment of traffic safety on highways as a result of changes in wheel track deformations on asphalt concrete pavements under the influence of natural and climatic factors, the strength of the pavement, the coefficient of adhesion on the pavement surface, and the smoothness of the pavement.

The construction and operation of asphalt concrete pavements on highways requires an approach in accordance with the requirements of SHNK-2.05.02-07, SHNK 3.06.03-08, and KMK 3.06.03-96. Taking the above into account, the issues of improving traffic safety in the territory of "Tashkent Avenue," which passes along the M-39 highway of international importance, were thoroughly analyzed. In this area, the high density of traffic flow, high traffic speeds, and the high level of interaction between pedestrians and vehicles were assessed as the main factors increasing the risk of road accidents.

The main goal of the research was to assess the anti-slip properties of the road surface by determining the adhesion coefficient and, on this basis, to scientifically substantiate the level of traffic safety. For this purpose, one of the modern measurement methods widely used in determining the technical and operational condition of road surfaces - the Cooper Pendulum Skid Resistance Tester (CRT pendulum) device - was used. Measurements were carried out on various sections of the road surface using the CRT pendulum device, taking into account real operating conditions. During the measurement process, micro- and macro-irregularities of the coating surface, properties of friction in dry and wet states were determined, and quantitative values of the adhesion coefficient were recorded. The obtained results were compared with the requirements of

current regulatory and technical documents, and the level of road surface traffic safety was assessed.

The analysis results showed that a decrease in the clutch coefficient leads to an increase in the braking distance of vehicles, a decrease in control stability, and an increase in the probability of road accidents, especially in humid conditions. Therefore, it is important to constantly monitor this indicator and take timely engineering and technical measures in cases of deviation from the established norms. The texture of the road surface characterizes such factors as the noise level caused by the interaction between the tire of the car wheel and the pavement, the comfort of the seats inside the vehicle, the quality of adhesion, resistance to sliding, and tire wear.

One of the factors that significantly affects traffic safety on highways is the adhesion quality of the pavement surface. According to the analysis of statistics of road traffic accidents (RTA) caused by road conditions, failure to ensure the quality of adhesion leads to the occurrence of up to 40% (RTA) [1]. This indicator is an important property of the pavement surface, reflecting the interaction of the vehicle with the pavement surface. Because the clutch force ensures the safe deceleration and stopping of the car. The adhesion force formed in the contact zone between the tire and the surface of the coating is called sliding resistance.

The texture of the pavement surface is one of the most important transport and operational indicators of the road, causing vehicle wheel adhesion to the pavement. The textures and frequencies of various pavement surfaces by the World Road Association are presented in Table 1.1 (Descornet 1990).

1.1- schedule

Lining surface properties	**Frequency range**	
	Wavelength	**Wave frequency (cycles/m)**
Microtexture	<0.5 mm	>2.000
Microtexture	0.5-50 mm	20-2.000
Microtexture	50-500 mm	2-20
Smoothness	0.5-50 m	0.02-2



Figure 1. View of the texture of the road surface (asphalt concrete)

Quality of road surface adhesion. The quality of road surface adhesion is an important indicator affecting the safety of vehicle traffic. In the Republic of Uzbekistan, the quality of adhesion is assessed by the magnitude of the adhesion coefficient. The coefficient of adhesion is understood as the ratio of the maximum shear stress acting along the road in the contact area of the road surface with the blocked wheel to the normal reaction in the contact area of the wheel and the pavement.

$$\varphi_x = \frac{R_{x\,max}}{R_z} = \frac{P_{tis}}{R_z} \qquad (1)$$

When determining the driving mode of a car moving in traction mode, it is necessary to find the maximum value of the horizontal reaction, equal to the force of adhesion of the wheel to the road. The ratio between the force of adhesion in a moving wheel and the vertical reaction is called the coefficient of longitudinal adhesion of the tire to the road and is denoted by. Fig. 2 shows a diagram of the forces acting on the driving wheel of a car moving uniformly on a hard surface. In this case, the vehicle wheel is subjected to vertical loads, vertical reactions, pushing forces, and resistance forces to oscillations directed opposite to the pushing force.

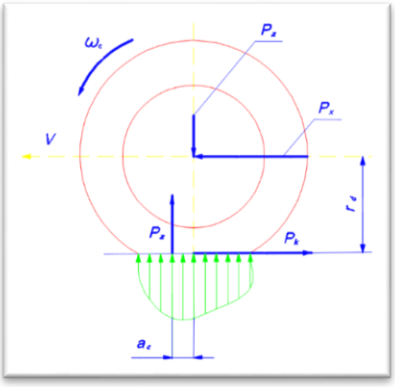


Figure 2. Diagram of forces during the movement of a car wheel

The value of the coupling coefficient depends on many factors. Its value is affected by:

- coating roughness;
- speed of the measuring device;
- complete or partial wheel blockage;
- contamination of the coating;
- air temperature, etc.

As a study, the adhesion quality of the road surface of the Tashkent highway of the international highway M-39 was determined using a British pendulum. "Cooper Pendulum Skid Resistance tester CRT pendulum" is a device that measures the coefficient of adhesion of road surfaces and is considered a leader in this field. Manufactured in the British Kingdom. The mechanical device is designed to determine the coefficient of adhesion of road surfaces not only in a dry state, but also in a wet state. This device is very easy to use and has high accuracy compared to other methods for determining the coefficient of adhesion of road surfaces. The "Cooper Pendulum Skid Tester" device was first improved in 1960 in the United Kingdom's transport exploration laboratory to determine the coefficient of adhesion of road surfaces. The device is designed for engineers to assess the coefficient of adhesion of the surface of the pavement in laboratory and real conditions in wet and dry conditions.

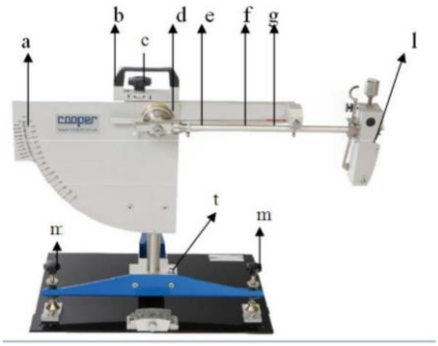


Figure 3. The main components of the device are:

a) counting system;

b) handle;

c) pendulum lowering-lifting screw;

d) needle securing-releasing screw;

e) lever;

f) needle;

g) needle tip;

l) rubber sample tested for friction and wear;

m) auxiliary screws (used to ensure the device stays level on the surface using a circular needle);

n) circular needle.

As a result of the conducted research, the coefficient of adhesion of the road surface was determined using the "Cooper Pendulum Skid Tester" device on the 23-24 km section of Tashkent Avenue, which passes along the M39 international highway. The measurement results are presented in the following graph (Fig. 4). The following reduction formulas were used to determine the coefficient of adhesion of the road surface. Formula for the coefficient of adhesion for 50 km/h

PSV=S+52.2-C

here. C - the average value of the obtained 4 test results, C - the average value of the obtained 4 test results. The values in Table 1.2 are used, which are evaluated by the coefficient of adhesion of dangerous sections of the highway.

1.2-table

Adhesion coefficient:	PSV≤50	50≤ PSV≤65	PSV≥65
Permissible lane markings	unsatisfactory	good	excellent

Formula for the coefficient of adhesion for 60 km/h

FR60=FRS*exp (60-S/Sp)

FRS - the average value of the results of 4 tests obtained

exp - constant value

S - 10 km/h for the Cooper Pendulum Skid Tester device Sp - car speed

For a speed of 60 km/h, the constant minimum value of the adhesion coefficient should not be less than 50.

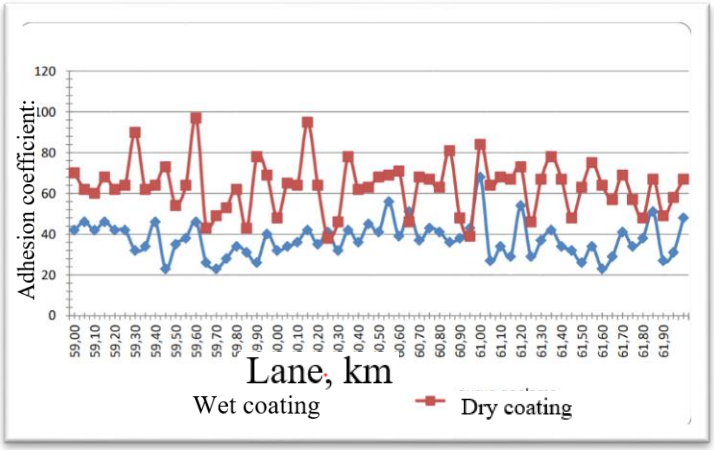


Figure 4. Change in the coefficient of adhesion of the road surface depending on the condition of the surface of the pavement.

From the analysis of the results of the study of the adhesion coefficient of the pavement of sections 23 - 24 km of Tashkent Avenue, passing along the international highway "M39," the following conclusions are drawn:

Conclusion

Based on the analysis of the conducted research and measurement results, it can be concluded that the adhesion properties of the road surface on some sections of Tashkent Avenue between 23-24 km, passing along the M-39 highway of international importance, do not meet the level of current regulatory requirements. This situation is explained by the insufficient timely maintenance and repair of the road surface. In particular, on sections from 23+10 km to 24+10 km, as well as at points 23+60, 23+75, 23+80, 23+90, 24+00, 24+10, and 24+20 km, a decrease in the adhesion coefficient was revealed, and it was noted that these sections have reached an unsatisfactory state. This reduces the interaction of vehicles with the road, decreases the speed of movement, limits the possibilities of ensuring traffic safety, and increases the probability of road accidents.

At the same time, it was established that the clutch coefficient on the remaining sections of the road studied within the framework of the study meets the normative values, and it was determined that safe movement of vehicles at specified speeds can be ensured on these sections. To increase the surface roughness of the coating, it is recommended to use modern technological machines for synchronous material distribution (Chipsiler 19, C hipseler 26, Chipseler 32, Chipseler 40 and Regis 19, Regis 26), manufactured in France. Timely implementation of repair and maintenance work on highways leads to an increase in the service life of roads, ensures traffic safety, and reduces costs.

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IMPROVING PROSTHETIC LIMBS IN UZBEKISTAN USING 3D PRINTING AND ONLINE CONSULTATIONS TO REDUCE COST, DECREASE WEIGHT, AND SIMPLIFY MANUFACTURING

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https://doi.org/10.5281/zenodo.19704399

Abstract. *Problem Statement. Limb prosthetics remain one of the most pressing medical and social issues in Uzbekistan. Over 22,000 citizens require prosthetic and orthopedic care; however, the state system predominantly provides only cosmetic, functionally limited devices. Traditional prosthesis manufacturing methods are characterized by high costs, significant structural weights, and lengthy production times. Methodology. This study analyzes domestic and international experiences in applying additive manufacturing technologies (3D printing) in prosthetics and examines the potential of telemedicine and remote consultations as tools for patient support in regional areas. Main Results. It was established that the implementation of FDM and SLS 3D printing methods reduces the cost of a limb prosthesis several times compared to traditional manufacturing, decreases product weight through topologically optimized designs, and shortens the production cycle. Online consultations ensure access to specialized care for patients from remote regions. Conclusion. The combined use of 3D printing and telemedicine technologies opens a realistic path toward the democratization of prosthetics in Uzbekistan and improvement in the quality of life of people with disabilities.*

Keywords: *3D printing, prosthetics, additive manufacturing, telemedicine, online consultation, rehabilitation, Uzbekistan, disability.*

Introduction.

Loss of a limb is one of the most severe functional impairments, fundamentally altering a person's daily life and activities. Despite the existence of state programs for providing prosthetic and orthopedic devices, the actual situation in Uzbekistan remains unsatisfactory. According to the available data, more than 22,000 citizens of the republic require prosthetics, of whom over 5,000 need upper-limb prostheses. Meanwhile, the state effectively provides only cosmetic prostheses — mannequin-like replicas devoid of functionality and incapable of supporting a full life. Bionic prostheses are not produced at the state level, and private initiatives face administrative, financial and technological barriers.

One of the few inspiring examples of domestic practice is the work of the student startup InnoGroup, which has been developing and printing bionic prostheses for hands, legs, and fingers using its own 3D printers since 2018. This experience clearly demonstrates that additive manufacturing technology is not only technically applicable in Uzbekistan but also significantly reduces the cost of the final product compared to traditional methods.

Simultaneously, digital healthcare is actively developing in the Republic. The "Digital Uzbekistan — 2030" strategy, approved by Presidential Decree No. UP-6079, dated 05.10.2020,

establishes the legislative and infrastructural foundation for the introduction of telemedicine, remote consultations, and the exchange of medical data between institutions. This creates prerequisites for organizing online support for prosthesis patients, particularly in regions far from major rehabilitation centers.

Thus, the combination of 3D printing as a manufacturing tool and telemedicine as a patient support tool represents a promising model capable of systematically improving the prosthetic situation in the country. This study aims to substantiate this model and analyze its potential within the context of Uzbekistan.

Literature Review.

Global experience has convincingly demonstrated the effectiveness of 3D printing in prosthesis manufacturing. Additive technologies make it possible to create products with precise consideration of the anatomical characteristics of a specific patient based on three-dimensional (3D) scanning or computed tomography data. Compared with traditional methods, the cost of such a prosthesis can be reduced by tens of times, and the deviation from the patient's anatomy does not exceed 1 mm. In Uzbekistan, the application of 3D technologies in medicine is still limited, primarily in dentistry and surgical planning. The comprehensive application of additive technologies in limb prosthetics, combined with the integration of telemedicine support, has not been sufficiently studied in the domestic scientific literature.

Methodology.

This study was conducted using a comprehensive analytical approach. In the first stage, a systematic analysis was performed on publications on the use of 3D printing in prosthetics, indexed in the PubMed, CyberLeninka, and Google Scholar databases for the period 2018–2024. In the second stage, Uzbekistan's regulatory and legal framework in the field of prosthetics and digital healthcare was examined, including relevant presidential decrees and cabinet of ministers resolutions.

In the third stage, a comparative analysis was conducted of the characteristics of prostheses manufactured using traditional methods and 3D printing across three key parameters: production cost, structural weight, and duration of the production cycle. PLA and PETG polymer filaments, as well as powder materials for SLS printing, were considered as the material basis, as they are the most accessible and applicable options in Uzbekistan. In the fourth stage, existing telemedicine support models for prosthesis patients in countries with similar infrastructure were analyzed, and their applicability to the conditions of Uzbekistan was assessed.

Research results. Cost Reduction. The traditional production of a functional below-knee prosthesis in Uzbekistan, accounting for the import of components, costs 3–8 million soums and above, whereas the estimated cost of an equivalent product manufactured by FDM printing from PETG filament does not exceed 400–700 thousand soums. This difference is primarily due to the elimination of milling, casting, and transportation costs. Importantly, equipment costs are recouped, on average, within two years of serial production, after which the unit cost drops sharply.

Results.

Weight Reduction. The application of topological optimization in digital design makes it possible to create internal prosthesis structures (lattice and honeycomb) that maintain mechanical strength while significantly reducing material consumption. According to foreign research data, 3D-printed below-knee prostheses weigh, on average, 30–45% less than traditional analogs made from polypropylene and metal components. Weight reduction directly affects energy expenditure during walking, patient fatigue, and willingness to wear the prosthesis for extended periods.

Simplification of Manufacturing. The digital workflow fundamentally changes the logic of prosthesis production. The traditional process involves casting the residual limb in plaster, creating a mold, manually forming the socket, and subsequent fitting, a process that takes two to four weeks. With 3D printing, a digital scan of the residual limb is sufficient, which can be performed using a budget scanner or photogrammetric smartphone application. The resulting model was adjusted in a CAD environment and sent to the printer. The finished product can be obtained within one–three days. This fundamentally changes the situation for patients from regional areas, who currently must travel to Tashkent or Samarkand for prosthetic fittings.

The Role of Online Consultation. Telemedicine support addresses not the production but the clinical aspects of the problem. After receiving a prosthesis, patients require regular socket adjustments, gait training, assessment of residual limb condition, and psychological support. In conditions where the only qualified prosthetist is hundreds of kilometers away, online video consultations allow for visual examination, fitting recommendations, and timely referral to an in-person appointment in the event of a complication. The development of the ZiyoNET and Moodle platforms within Uzbekistan's medical education system demonstrates that the technical infrastructure for such communication already exists in the republic.

Discussion. Discussion of Results. These findings are consistent with the global practice of implementing additive technologies in rehabilitation medicine. Notably, the experience of the student startup InnoGroup demonstrates that even without state support, a team of enthusiasts is capable of establishing the production of functional 3D-printed prostheses in Uzbekistan and winning a national startup competition with this project. This attests to the real rather than theoretical potential of this technology.

Assessment. First, the mechanical strength of polymer materials available for FDM printing (PLA and PETG) is inferior to that of professional prosthetic components made of carbon fiber or titanium alloys. This currently limits the use of fully 3D-printed prostheses to moderately active patients, partial amputations, and temporary or training devices. For patients with high physical loads, hybrid constructions are more appropriate at this stage, where a 3D-printed socket is combined with factory-made joints and pylon.

Second, the quality and accuracy of digital scanning of the residual limb in regional medical institutions directly depend on the availability of modern equipment and personnel qualifications. In many districts of the republic, only budget smartphone-based photogrammetry applications are realistically available, which can lead to inaccuracies in the socket fit and the need for repeated adjustments. Therefore, systematic training of specialists and the gradual equipping of regional centers with affordable 3D scanners are critical.

Third, the effective functioning of the online consultation system requires a stable and sufficiently high-speed Internet connection, which is not always guaranteed in remote areas of Uzbekistan, especially in mountainous and desert regions. Unstable connectivity can significantly reduce the quality of visual assessment of prosthesis fit and gait, thereby limiting the real accessibility of telemedicine.

Discussion Conclusions.

The described model is most effective when implemented in stages: in the first stage — the establishment of regional 3D laboratories at medical universities (analogous to the digitalization initiatives of the Tashkent Medical Academy); in the second stage — the integration of telemedicine platforms for post-prosthetic patient support; in the third stage — the development

of domestic standards and a regulatory framework for the certification of 3D-printed medical devices.The proposed model is most effective when implemented in a phased manner.

In the first stage, it is advisable to establish specialized 3D printing laboratories based at leading medical universities and major republican centers (Tashkent, Samarkand, Andijan, and Bukhara), relying on the successful experience of the student startup InnoGroup as a pilot project. This will allow for the accumulation of practical expertise and training of the first cohort of specialists who combine medical and engineering competencies.

In the second stage, it is necessary to integrate existing telemedicine platforms (ZiyoNET and others) into the prosthetics process by developing standardized protocols for remote socket adjustment, video gait analysis, and psychological support. At this stage, pilot projects can be launched in several regions to test the full patient pathway, from scanning to long-term online follow-up.

In the third stage, national standards and a regulatory framework for the certification of 3D-printed medical devices should be developed and approved. This includes defining the requirements for materials, strength testing methods, clinical trials, and liability issues. Only after resolving the regulatory issues will it be possible to fully integrate 3D-printed prostheses into the state rehabilitation program and ensure sustainable funding for the program.

Conclusion. The analysis shows that the combination of 3D printing technology and telemedicine online consultations represents a practically feasible and economically justified alternative to the existing prosthetic system in Uzbekistan. A threefold or greater reduction in product cost, a reduction in weight of up to 45%, and a shortening of the production cycle from weeks to days are not abstract prospects but documented results confirmed by both global experience and individual domestic precedents.

Systemic improvement of the situation requires concrete measures, such as the inclusion of 3D prosthetics in state rehabilitation programs, funding of regional laboratories at medical institutions, formation of a regulatory framework for the certification of additively manufactured prostheses, and training of specialists combining medical and engineering competencies. The digital transformation of healthcare, declared at the state level, must encompass not only diagnostics and education but also rehabilitation, a sphere in which thousands of citizens await real change.

An important direction for further development is the integration of artificial intelligence tools into prosthetic design workflows. AI-assisted CAD systems can automate the generation of patient-specific socket geometries based on scan data, reducing the need for manual adjustment and minimizing fitting errors. Combined with 3D printing, this approach could make the entire production pipeline — from scan to finished device — fully digital and largely automated, further reducing both cost and time.

Furthermore, the long-term sustainability of the proposed model depends on the development of local-material supply chains. Currently, most polymer filaments used in FDM printing are imported, which creates a degree of dependence on external markets. Establishing domestic production of medical-grade PLA and PETG materials or expanding the use of locally sourced biodegradable polymers would significantly strengthen the economic resilience of the system and further reduce per-unit costs.

Finally, patient education must be recognized as an integral component of telemedicine. Remote consultations are most effective when patients understand basic maintenance procedures, can identify early signs of socket misfit, and are equipped with simple self-adjustment skills.

Developing accessible digital instructional materials in Uzbek and Russian, distributed through existing platforms such as ZiyoNET, would substantially enhance the outcomes of remote prosthetic care and reduce the frequency of emergency in-person visits to the clinic.

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DIGITAL TRANSFORMATION OF BUSINESS DECISION-MAKING: AN ALGORITHM FOR THE APPLICATION OF PRESCRIPTIVE ANALYTICS

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https://doi.org/10.5281/zenodo.19879402

Abstract*. The rapid digitalization of modern enterprises has significantly increased the complexity of business environments, requiring advanced analytical approaches to support effective decision-making. This study examines the role of prescriptive analytics in the digital transformation of business decision-making, with a particular emphasis on simulation modeling as a core methodological tool. The research aims to develop a generalized algorithm for constructing digital decision-making systems capable of analyzing complex and dynamic business processes. The study integrates multiple simulation approaches, including discrete-event simulation, agent-based modeling, and hybrid modeling, to support scenario analysis, resource optimization, and risk mitigation.*

A structured methodological framework is proposed, encompassing problem formulation, conceptual modeling, data modeling, experimental design, validation, and integration into digital platforms. The results demonstrate that simulation-based prescriptive analytics enables organizations to evaluate multiple decision scenarios without real-world risks, improving operational efficiency and strategic planning. Furthermore, the integration of simulation with optimization techniques enhances decision accuracy and adaptability. The study concludes that digital decision platforms based on simulation modeling significantly contribute to sustainable and data-driven business process management in dynamic environments.

Keywords: *prescriptive analytics, Simulation modeling, Digital decision-making, Business process optimization, Discrete-event simulation, Agent-based modeling, Hybrid simulation systems.*

1. Introduction

The transformation of business environments under the influence of digital technologies has fundamentally altered how organizations approach decision-making. Increasing levels of uncertainty, system complexity, and interdependence among processes require analytical tools capable of handling dynamic and stochastic conditions. Traditional decision-making approaches, which rely on historical data analysis and managerial intuition, are no longer sufficient for addressing the multifaceted challenges faced by modern enterprises.

Prescriptive analytics has emerged as a critical component of the analytics paradigm, extending beyond descriptive and predictive approaches by providing actionable recommendations based on advanced computational models (Delen & Zolbanin, 2018). Among the various techniques used in prescriptive analytics, simulation modeling has gained particular importance due to its ability to replicate the behavior of complex systems over time. Simulation modeling allows decision-makers to experiment with different scenarios in a controlled digital environment, thereby reducing risks and improving the quality of decisions.

Simulation modeling in business process management involves the creation of a digital representation of real-world systems that incorporates stochastic variables and dynamic interactions. Several modeling approaches are commonly used, including discrete-event simulation (DES), system dynamics (SD), and agent-based modeling (ABM). Discrete-event simulation focuses on sequential processes and event-driven changes, making it suitable for logistics and manufacturing systems (Banks et al., 2014). System dynamics provides a macro-level perspective by modeling continuous flows and feedback loops (Shannon, 1998), while agent-based modeling captures interactions among autonomous agents, enabling the analysis of emergent behaviors in complex systems (Wallentin & Neuwirth, 2017).

Despite the widespread application of these techniques, existing research often treats them as independent methodologies rather than components of an integrated decision-making framework. This fragmentation limits their effectiveness in addressing complex, real-world problems that require multi-level analysis and coordinated decision-making. Moreover, there is a lack of generalized algorithms that systematically integrate simulation modeling with optimization techniques to support prescriptive decision-making.

Business process reengineering (BPR) further highlights the need for advanced analytical tools. Redesigning business processes requires a comprehensive understanding of current operations, resource allocation, and potential future scenarios. Testing alternative configurations in real-world conditions is often impractical due to high costs and associated risks. Simulation modeling offers a viable alternative by enabling virtual experimentation and performance evaluation under controlled conditions.

Therefore, this study aims to address the existing research gap by developing a generalized algorithm for the application of prescriptive analytics through simulation modeling. The proposed framework integrates multiple modeling approaches and provides a structured methodology for building digital decision-making systems capable of optimizing business processes and supporting strategic decision-making.

2. Methodology

This study adopts a conceptual and methodological research design aimed at developing a comprehensive algorithm for prescriptive analytics based on simulation modeling. The proposed methodology is grounded in established principles of operations research and systems analysis, incorporating best practices from existing literature on simulation modeling and optimization techniques (Law, 2007; Pritsker, 1998).

The research process begins with **problem formulation**, which involves clearly defining the objectives of the study and identifying the key variables and constraints of the system under consideration. This stage ensures alignment between analysts and decision-makers and provides a foundation for subsequent modeling activities. It is important to note that problem formulation is often iterative, as new insights may require adjustments to the initial problem definition.

The next stage involves **defining research objectives and developing a project plan**. This includes identifying the specific questions to be addressed through simulation modeling and determining whether simulation is an appropriate methodology for the given problem. The project plan outlines the scope of the study, including the number of scenarios to be analyzed, required resources, and expected outcomes.

Model conceptualization follows, where the system is abstracted into a simplified representation that captures its essential features. This process involves identifying system components, defining relationships among variables, and selecting the appropriate modeling

approach. Depending on the nature of the system, a discrete-event, agent-based, system dynamics, or hybrid modeling approach may be used. Conceptual modeling should strike a balance between simplicity and accuracy to ensure that the model remains both manageable and representative of the real system.

The **construction of the digital model** involves translating the conceptual model into a computer-readable format using specialized simulation software. Tools such as AnyLogic, FlexSim, and AutoMod are commonly used for this purpose. This stage requires careful consideration of computational requirements and model scalability.

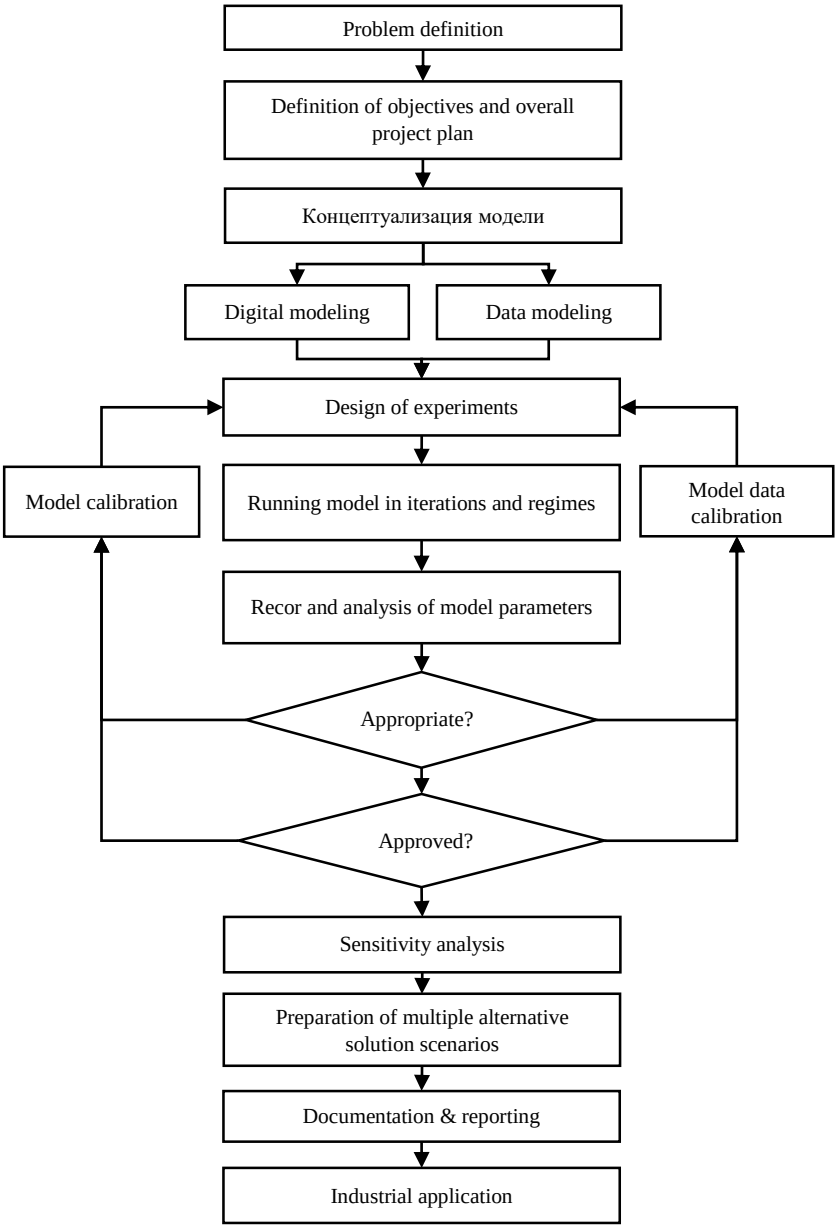


Figure 1. A general algorithm for implementing prescriptive analytics for building a digital decision-making system.

Data modeling is conducted concurrently with model construction. This stage involves collecting, processing, and analyzing input data required for the simulation. Data may be obtained through electronic recording systems, direct observation, or expert assessment. Statistical analysis is used to determine data distributions and ensure that the model accurately reflects real-world conditions (Gavilan et al., 2021).

The **experimental design** phase defines the parameters of the simulation, including the duration of simulation runs, number of iterations, and variation of input variables. Multiple simulation runs are conducted to account for stochastic variability and ensure the reliability of results (Sanchez, 2007).

Model verification and validation are critical steps in ensuring the accuracy and reliability of the simulation model. Verification involves checking that the model is implemented correctly, while validation ensures that the model accurately represents the real system. Validation may involve comparing simulation outputs with real-world data or relying on expert judgment when empirical data are unavailable (Sargent, 2007).

A **sensitivity analysis** is then performed to evaluate the impact of changes in input variables on system performance. This analysis helps identify critical variables and assess the robustness of the model under different conditions.

Finally, the results are integrated into a **digital decision-making platform**, where alternative scenarios are evaluated, and optimal solutions are identified. This integration enables real-time decision support and enhances the practical applicability of the simulation model.

3. Results

The application of the proposed methodology resulted in the development of a generalized algorithm for implementing prescriptive analytics in business decision-making. The algorithm consists of a sequence of interconnected stages, including problem formulation, conceptual modeling, data modeling, experimental design, simulation execution, validation, sensitivity analysis, and integration into a decision-support system.

The results demonstrate that simulation modeling provides a robust framework for analyzing complex systems and evaluating alternative decision scenarios. By enabling virtual experimentation, simulation reduces the risks associated with real-world testing and allows organizations to identify optimal strategies for resource allocation and process optimization.

The integration of optimization techniques with simulation modeling further enhances decision-making capabilities. Optimization methods enable the identification of the best configuration of system parameters, improving performance metrics such as efficiency, cost, and service quality (Collison, 2022). This combination of simulation and optimization provides a powerful tool for prescriptive analytics.

Additionally, the use of hybrid simulation models allows for a more comprehensive representation of complex systems by combining the strengths of different modeling approaches. For example, integrating discrete-event simulation with system dynamics enables the modeling of both operational processes and strategic-level interactions. Similarly, combining agent-based modeling with other approaches allows for the analysis of individual behaviors and their impact on system-level outcomes.

The results also highlight the practical applicability of the proposed algorithm across various industries, including logistics, manufacturing, energy systems, and e-commerce. Simulation-based decision-making systems can be used to optimize delivery services, improve production efficiency, and support strategic planning in dynamic environments.

4. Discussion

The findings of this study underscore the transformative potential of prescriptive analytics and simulation modeling in modern business environments. The proposed algorithm provides a systematic framework for integrating simulation models into digital decision-making platforms, enabling organizations to make informed and data-driven decisions.

One of the key advantages of simulation modeling is its ability to capture the dynamic and stochastic nature of real-world systems. This allows decision-makers to analyze the impact of various factors on system performance and identify potential bottlenecks and inefficiencies. Furthermore, the integration of optimization techniques enhances the effectiveness of simulation models by identifying optimal solutions based on predefined criteria.

The use of hybrid simulation models represents a significant advancement in modeling complex systems. By combining different modeling approaches, hybrid models provide a more comprehensive understanding of system behavior and improve the accuracy of predictions. This is particularly important in industries where systems are highly interconnected and influenced by multiple variables.

The integration of artificial intelligence and machine learning into simulation modeling presents additional opportunities for improving decision-making processes. These technologies can automate the optimization process, reduce computational time, and enhance the adaptability of decision-making systems (Alalwan, 2020).

However, several challenges remain. The development of simulation models is a complex and time-consuming process that requires significant expertise and computational resources. Data availability and quality also play a critical role in determining the accuracy of simulation results. Furthermore, the successful implementation of simulation-based decision-making systems depends on the involvement of end users throughout the modeling process and their understanding of the model's outputs.

5. Conclusion

This study demonstrates that prescriptive analytics, supported by simulation modeling, plays a crucial role in the digital transformation of business decision-making. The proposed algorithm provides a comprehensive framework for developing digital decision-making systems capable of analyzing complex business processes and supporting optimal decision-making.

Simulation modeling enables organizations to evaluate multiple decision scenarios without real-world risks, improving operational efficiency and strategic planning. The integration of optimization techniques further enhances decision accuracy and adaptability, allowing organizations to respond effectively to changing environments.

In conclusion, the implementation of simulation-based prescriptive analytics contributes significantly to the development of effective digital decision-making platforms. These platforms enable organizations to navigate complexity, optimize resources, and achieve sustainable competitive advantages in an increasingly dynamic business landscape.

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RESEARCH OF LIMIT LOADS IN OPPOSITE FLOWS IN ABSORPTION PURIFICATION OF GAS AND LIQUID FLOWS OF NATURAL GASES

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https://doi.org/10.5281/zenodo.20068192

Abstract. *It has been scientifically substantiated that during the absorption purification of gas and liquid flows, the free volume of natural gases decreases during their two-phase movement, and tangential stresses arise on the contact surface of the phases as a result of friction during their movement. As a result of research, it has been proven that in such a process, when the gas flow moves upward, the gas velocity decreases due to the movement of the flow backward and the force of gravity of the liquid. The obtained results prove that with a further increase in the gas velocity, the liquid begins to grow into the nozzle, and the possibility of determining it as a turbulization mode of a two-phase system on the surface of the hydrodynamic regime has been proven, and the processes of its application in the purification of natural gases at the "Shurtan Oil and Gas Production Department," "Mubarek Gas Processing Plant," "Shurtan Gas Chemical Complex," and "Ustyurt Gas Chemical Complex" due to its high selectivity have been investigated.*

Keywords*: natural gas purification, absorption process, two-phase flow, hydrodynamic regime, tangential stress, turbulization mode, gas-liquid interaction, selective purification, mass transfer, gas processing plants.*

Introduction. In the two-phase motion of a gas and liquid, the free volume decreases, and as a result of friction, tangential stresses arise on the contact surface of the phases. During two-phase motion, the interaction between the phases leads to an increase in the hydraulic resistance of the AP compared to the dry (non-irrigating) nozzle. This interaction can be neglected only at low-phase speeds. When gas and liquid move in opposite directions, four different hydrodynamic regimes are distinguished depending on the flow velocity (Fig. 1).

The first (section A), called curtain mode, occurs at low loads of gas and liquid. In this mode, the phase interaction is insignificant, and the amount of held fluid (US - holding capacity) does not depend on the gas velocity. Section A, representing the resistance of the irrigation nozzle, is a parallel line for dry nozzle I and is located above the nozzle with increasing irrigation density. Some researchers[1] note that this mode is one.-

Above the 1st braking point, an intermediate fluid regime can occur during movement (Fig. 1, section B). The liquid covers the nozzle in the form of a thin flowing film and separate streams. Interfacial interaction occurs on the surface of the film and liquid flows and at the points where the liquid contacts individual elements of the nozzle. In film and fluid flows, a slowdown is observed with the formation of individual gas flow vortices [2].

With a further increase in the gas velocity, the liquid begins to grow on the nozzle (point of suspension 2), while the opposite flow is held by the moving gas. An increase in US with an increase in gas velocity leads to a decrease in the free volume of the nozzle and a rapid increase in resistance. The liquid and gas phases interact on the surface of the turbulent fluid film and therefore

can be defined on the surface of the hydrodynamic regime as the turbulent regime of a two-phase system (section B).

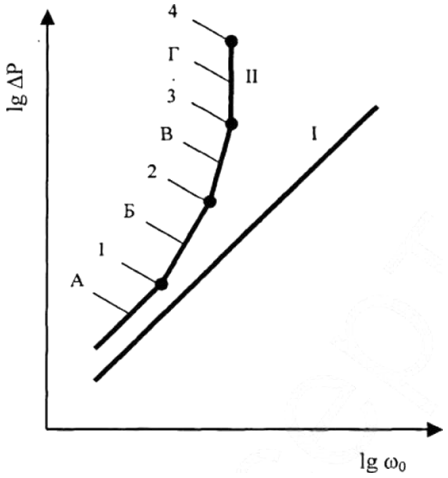


Figure 1 - Hydrodynamic regimes for a two-phase system in the columns of a two-tailed nozzle and their transition points:
I - for dry nozzles, II - during irrigation; A - curtain mode; B-intermediate mode; B-turbulence mode of the two-phase system; G-emulsification mode; 1 - stability point; 2 - hanging point; 3 - phase acceleration point; 4 - suffocation point.

Further accumulation of the liquid in the nozzle, the interaction between the flows and the wetted surface of the nozzle leads to its transition into its volume. The accumulation of liquid mainly begins at the bottom of the nozzle and gradually spreads throughout the entire height. This is characterized by the emergence of a fundamentally new hydrodynamic regime - the emulsification regime (section G).

Emulsification mode - a field of free enhanced turbulence - occurs in the packing columns after the phase intensification point. Increased turbulence in each phase of the packing volume leads to turbulent pulsations of the phase separation surface. In this mode, the concept of dispersed and continuous phases loses its meaning, since the phases are constantly inverted, transforming into gas or liquid, continuous or dispersed phases. In this case, the phases pass in countless small whirlpools[2].

Under such conditions, a stable hydrodynamic system of "emulsified" liquid exists, in which constantly arising and moving gas vortices penetrate the circulating liquid, in which liquid vortices also constantly arise and move. Unlike the first two points (gas stability point and liquid suspension point), the acceleration point is always sharply visible and clearly defined.

According to the studies of Planovsky and Kafarov [3], as well as a number of other authors [4, 5, 6], the choking mode corresponds to the maximum efficiency of the nozzle column column. High efficiency in the choking mode is explained by the large contact area of the phases, which in this mode is determined not by the geometric surface of the nozzle, but by the conditions of the impacts.

The 4th choking point corresponds to conditions in which the height of the gas-liquid (vapor-liquid) emulsion layer is greater than the height of the packaging layer, and a liquid layer accumulates above the nozzle, which is a foam layer with sedimentary mixing.

The final mode (cultivation mode) occurs when the gas velocity exceeds the value corresponding to the counter-current mode. In this case, an intensification of the secondary phase occurs: the gas again transforms into a continuous phase, and the liquid, along with the gas, is carried out from the apparatus, mainly in the form of splashes. Simple filling irrigation.

The specified mode is accompanied by a sharp decrease in the intensity of mass transfer. Access mode is practically not used and therefore is practically unexplored. According to work [3], in this mode, the increase in resistance slows down, and the curve of DR's dependence on gas

velocity proceeds with approximately the same slope as in curtain mode. The point corresponding to the transition to input mode characterizes the maximum loads of the device.

Experimental studies by many authors [2, 7, 8, 9] on the determination of the suffocation point were determined by the following regularities:

1) With an increase in irrigation density, suffocation occurs at a lower gas velocity. In the absence of gas movement, a dependence was observed at very high irrigation densities.

2) With the same irrigation density, the gas velocity corresponding to choking is higher at higher values of the equivalent nozzle diameter.

3) With the same dimensions of the packing elements, the lower the load limit for gas and liquid, the lower the empty volume of the packing.

For packing columns, the critical state is considered to be maintained (accumulation of liquid in the packing) or evaporation of the packing (when the liquid layer accumulates over the winding, which is a foam layer with rapid mixing) [2].

At the limit load of the column, the final loads of the packing columns are determined according to the same laws as in traditional packing columns, but in most cases, the beginning of the suspension mode is taken as an important point in the operation of the packing [2, 9].

Thus, taking into account the foregoing, the objectives of studying the maximum loads of the developed two-tailed packing column include:

The velocity of the gas phase corresponding to the beginning of the suspension regime in the layer of the two-tailed nozzle column, as well as other studied nozzles (for comparison with the usual: an irregular nozzle made of angular and X-shaped and Rashig rings - a column of two-tailed nozzles) are determined by the gas flow and liquid phase.

- a mathematical model is found that adequately describes the results obtained as a result of experimental studies.

According to the adjustment shown in Fig. 1, to determine the velocity of the gas phase in the entire cross-section of the column, corresponding to the start of the holding mode. The obtained data are presented in the table.

The values of the gas phase velocity corresponding to the hanging mode of the Rashig rings for the nozzle were calculated using the generally accepted Beyne-Hougen equation [2, 8, 9, 10, 11] for experimental conditions:

$$\lg\left[\frac{\omega_r^2 \cdot f}{g \cdot \varepsilon_{CB}^3} \cdot \frac{\rho_r}{\rho_æ} \cdot \mu_æ^{0,16}\right] = \hat{A} - \tilde{N} \cdot \left(\frac{W_{Æ}}{W_r}\right)^{0.25} \cdot \left(\frac{\rho_r}{\rho_æ}\right)^{0.125} \quad (1)$$

here ω_r - gas velocity in the entire column cross-section, m/s;

ε_{CB} - Free volume of packaging, m^3/m^3;

f - specific surface area of the nozzle per unit volume, m^2/m^3.

ρ_r, $\rho_æ$ - density of gas and liquid phases, kg/m^3; - dynamic viscosity of the liquid phase, Pa-s; W_r,

W_J - mass flows of gas and liquid phases, kg/ (m-hour);

B and C - corresponding coefficients for different types of nozzles.

For Raschig rings of the selected size (ceramic, 25x25x3), according to various sources, the following data are provided. [2, 8, 9, 11]: = 0,74 m^3 / m^3; f = 200 m^2 / m^3.

Coefficients of equation 3.1 for the condition of the beginning of the gas suspension regime in the layer of the nozzle column [12]: B = - 0,073 and C = 1,75.

Conducting a series of parallel experiments using blocks of a transparent nozzle column according to the method described in Section 3.5 of this dissertation for the studied continuous nozzles showed that the beginning of the gas-phase suspension mode is determined uniquely within the range of the gas and liquid phase flow rate measurement error of no more than 3% (Table 1, Appendix A). Thus, it can be assumed that the values of the gas phase velocity in the entire cross-section of the experimental column, presented in Table 1 (Appendix A), can be completely reliably repeated.

The graphs in Fig. 1 show that the velocity of the beginning of the suspension mode in bi-tailed and angular nozzles between the most common gas and liquid loads is practically the same (rows 1 and 2). This circumstance can be explained by the anatomical structure of the column of the tested nozzles. Double-tailed and simple-angled nozzles also have a strictly defined cellular structure of the nozzle column structure. The gap size for both nozzles was 0.015 m.

According to the experimental values of the critical velocity in the entire cross-section of the column for the tested nozzles, presented in Table 1, graphical dependencies are constructed in Fig. 2.

Data on gas phase velocity ω_r corresponds to the beginning of the hanging mode in the full section of the column.

Table 1

$(W_{Æ} / W_{r})$	L/G	Double-tailed nozzle	X-shaped nozzle	Angular nozzle	Rashig rings
1	2	3	4	5	6
5,359	0,0065	1,177	0,969	1,159	0,939
5,824	0,0070	1,146	0,946	1,127	0,914
6,306	0,0076	1,116	0,923	1,097	0,889
6,807	0,0082	1,087	0,902	1,069	0,866
7,327	0,0088	1,059	0,882	1,042	0,843
8,834	0,0106	0,990	0,831	0,974	0,788
9,429	0,0114	0,967	0,813	0,950	0,768
10,049	0,0121	0,944	0,796	0,927	0,750
10,581	0,0128	0,925	0,782	0,909	0,735
11,371	0,0132	0,900	0,772	0,896	0,714
15,252	0,0184	0,798	0,686	0,784	0,633
20,235	0,0249	0,705	0,609	0,686	0,558
26,006	0,0313	0,627	0,553	0,615	0,495
33,475	0,0410	0,553	0,491	0,537	0,436
41,721	0,0503	0,492	0,446	0,482	0,387
52,300	0,0615	0,434	0,404	0,431	0,340
62,909	0,0758	0,389	0,362	0,381	0,305
85,979	0,1048	0,320	0,302	0,310	0,250

106,510	0,1282	0,277	0,268	0,271	0,216
134,369	0,1599	0,235	0,233	0,232	0,183
174,332	0,2102	0,194	0,194	0,188	0,150

From the experimental data presented in the form of graphs in Fig. 2, it can be seen that the X-shaped nozzle has a smaller range of maximum loads for gas and liquid, which is due to the design features of the nozzle. Thus, with the equality of the total area of the gap gaps, the width of the gaps marked on the X-shaped nozzle was 0.01 m.

The speed of starting the gas phase retention mode in the two-tailed nozzle device is 19% higher in the studied range, it should be noted that with an increase in the L/G ratio, the difference in the permissible gas velocity values decreases.

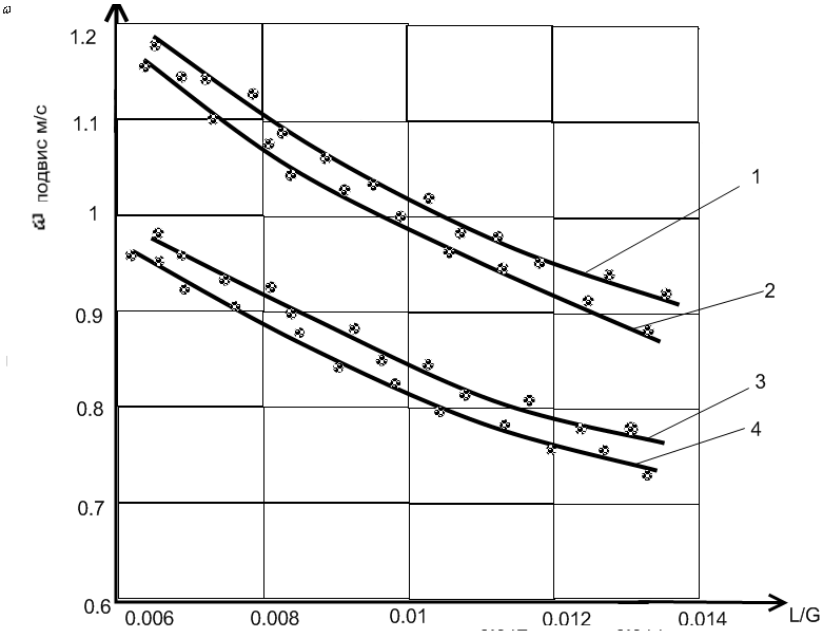


Figure 2. Comparison of initial suspension speeds in different nozzles.

1 - two-tailed nozzle; 2 - angular column; 3 - X-shaped nozzle; 4 - Rashig rings.

Conclusion

When comparing the values of the gas phase velocity, corresponding to the beginning of the suspension mode of suspension Re in the two-tailed gas-phase nozzle device, with the calculation for the Rashig rings, the difference was found to be from 20 to 22%. It should be noted that with an increase in the load of the liquid phase, the difference in the values of the suspension velocities of the two-tavr nozzle device and the Rashig rings increases.

From the experimental data, presented in the form of graphs, it can be seen that the X-shaped nozzle has a smaller range of maximum loads for gas and liquid flows, which is due to the design features of the nozzle. Thus, with the equality of the total area of the gap gaps, it was investigated that the width of the gaps marked on the X-shaped nozzle was 0.01 m.

Note that the speed of starting the gas phase shutdown mode in the two-tailed nozzle device is 19% higher in the studied range.

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SMART STOP – SOLAR PANEL BENCH

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Abstratct. *Modern cities are developing at a rapid pace, and this growth is significantly increasing the demand for energy efficiency and public convenience. Today, millions of people around the world spend time in public spaces — such as parks, bus stops, and boulevards — and most of them lack the opportunity to charge their mobile devices, access the internet, or simply relax comfortably. The need for innovative solutions to bridge this gap is becoming increasingly evident.*

Energy efficiency is important not only from an economic perspective but also from an environmental one. Reducing dependence on fossil fuels, lowering CO_2 emissions, and protecting the environment have become key priorities in modern urban management. In this context, the use of renewable energy sources, particularly solar energy, is recognized as one of the most promising directions.

Keywords*: solar energy, photovoltaic effect, solar panels, semiconductors, silicon, electricity, renewable energy sources, inverter, energy storage systems, environmentally friendly energy.*

Introduction

Modern cities are developing at a rapid pace, and this growth is significantly increasing the demand for energy efficiency and public convenience. Today, millions of people around the world spend time in public spaces — such as parks, bus stops, and boulevards — and most of them lack the opportunity to charge their mobile devices, access the internet, or simply relax comfortably. The need for innovative solutions to bridge this gap is becoming increasingly evident.

Energy efficiency is important not only from an economic perspective but also from an environmental one. Reducing dependence on fossil fuels, lowering CO_2 emissions, and protecting the environment have become key priorities in modern urban management. In this context, the use of renewable energy sources, particularly solar energy, is recognized as one of the most promising directions.

Energy Problem
The lack of charging facilities in public places remains a significant issue.

Environmental Necessity
The use of clean and renewable energy sources is essential.

Innovative Solution
Smart Stop is a modern device that simultaneously

Materials and Methods

Smart Stop – Solar Panel Bench is a modern solution designed to meet these needs. It not only provides a comfortable seating area in public spaces but also enables the charging of mobile devices using solar energy. This represents a perfect combination of technology and convenience, elevating urban infrastructure to a new level.

Part 1: What is "Smart Stop – Solar Panel Bench"?

Basic Concept: Smart Stop is a modern public bench equipped with solar panels that collect solar energy and provide users with the ability to charge their mobile devices. The device is autonomous — it does not require connection to an external power source.

This innovative solution enhances the functionality of public spaces and makes them more convenient for users. Unlike a regular bench, Smart Stop serves both as a resting place and an energy station at the same time.

Areas of Application:

- **City parks** — a convenient charging spot for visitors
- **Bus stops** — efficient use of waiting time
- **Boulevards** — an energy source for pedestrians
- **Shopping areas** — an additional service for customers
- **Educational institutions** — for students and pupils
- **Sports grounds** — for active (active visitors)

Technical Characteristics of Solar Panels:

The ASTRONERGY 550 W "A"-class solar panels used in the Smart Stop device meet the highest quality standards in the industry. These panels are distinguished not only by their high energy generation efficiency but also by their long-term reliability and stability

ASTRONERGY 550 W "A"-Class

Panels with the highest efficiency in the industry. The "A"-class certification confirms that the product fully complies with all technical requirements and meets the highest manufacturing standards.

One-Part Series Warranty

A 12-year product warranty and a 25-year linear power warranty ensure the reliability of these panels as a long-term investment. The manufacturer is confident in their product.

Manufacturer

Made by one of China's top solar panel manufacturers. Leading the world market and used in thousands of projects globally

Economic Efficiency

1 container can hold 620 550W panels. The price is $0.29 per watt, which is very competitive for large-scale projects.

The main components of the device. The Smart Stop device consists of several important components, each of which performs a specific function. All elements together form a complete and effective system

- Solar Panel: The main element of energy harvesting. It converts sunlight directly into electrical energy and drives the entire system.
- Battery: Designed to store the collected energy. It ensures the device works even on cloudy days.
- Charger: An intelligent control unit that transfers energy from the panel to the battery with maximum efficiency.
- USB Ports: Allows you to directly charge smartphones, tablets and other gadgets.
- Light (Optional): An LED light can be installed to ensure safety and convenience even at night.

Energy harvesting and storage capabilities. Solar energy is one of the most powerful and unlimited energy sources available to humanity. The amount of solar energy reaching the Earth's surface daily is twenty times greater than current global energy consumption, and harnessing this enormous potential has become a major focus of technological progress

Renewable: Serves as a continuous source of energy for approximately 6.5 billion years.

1. Abundance: The Earth's surface receives 20 times more solar energy than the current global energy consumption.

2. Consistency: The source of solar energy is stable, its amount can be calculated and predicted.

3. Availability: Works anywhere where there is natural light - both far from the city and in the mountains.

4. Environmental friendliness: Harmless, odorless and has no negative impact on the environment.

The principle of operation of the device. The operation of the Smart Stop device is based on a simple but very effective technological chain. Through the photovoltaic effect, sunlight is converted directly into electrical energy, which is then available to users.

Solar panels

Converts sunlight into electricity

Charging devices

Stored energy charges via USB ports.



Energy storage

The generated energy is stored in a battery.

This simple and effective process is carried out automatically. No technical knowledge or intervention is required from the user. The device collects energy during the day when there is

sufficient sunlight and continues to work at night or on cloudy days. This makes the Smart Stop a device that can provide stable and reliable service all year round.

Installation and location requirements. Proper placement and installation of solar panels is essential for them to operate at maximum efficiency. An improperly positioned panel may only be able to utilize a portion of its potential, significantly reducing the overall efficiency of the system.

Technical installation

Installation angle: It is calculated precisely depending on the geographical latitude of the location.

Configuration: The location of the panels relative to each other and the connection order play an important role.

Special equipment: Metrological instruments are used to ensure accuracy.

Satellite data: Used to determine the optimal angle for each location.

Results

Capabilities and areas of application. The Smart Stop device, due to its wide functionality, can be successfully used in various public places. Its main capabilities serve to make the lives of users more convenient and modern.

- Mobile device charging: Charge smartphones, tablets, headphones and other gadgets with free and environmentally friendly energy. Multiple devices can be charged simultaneously via USB ports.
- Public areas: Can be installed in parks, bus stops, alleys, waiting rooms and other public areas. Individual configuration is possible for each location.
- Ecological solution: Serves as a clean, renewable energy source without causing any harm to the environment. An important tool in reducing carbon footprint and implementing the green city concept.

Prices and availability: According to Smart-market.uz, the Uzbek market offers a wide range of solar panels and related equipment, offering solutions for various needs and budgets. Prices vary significantly depending on power, quality and manufacturer.

The minimum price of solar panels in the Uzbek market starts from 1.1M soums. The maximum price of premium class solar panels is up to 33M soums. The price of a ready-made solar panel kit (1 kilowatt of power) is 13M soums -1kW. The price of an ASTRONERGY 550 W panel (for 1 container) is $0.29 per Watt.

Panel type	Power	Price
Standard solar panel	150kW	-11 million soums
Medium power panel	540kW	2 million soums
High power panel	550kW	From 7.5 million soums
Ready-made kit	1kW	13 million soums

Important Note: All technical parameters are measured under standard test conditions (STC: 1000 W/m², 25°C temperature, AM 1.5 air mass). Actual performance may vary slightly.

Mechanical data (example): The mechanical parameters of a solar panel include its physical dimensions, weight, and material composition. These parameters are crucial for the design of the installation location and structure.

Cell Type: Monocrystalline 182 × 91 mm. Highest efficiency

Frame Material: Aluminum alloy, lightweight and strong, corrosion resistant

Glass Thickness: 3.2 mm. High durability. Anti-reflective coating

Module Size: L2278 × W1134 × H35 mm. Large active surface. Maximum energy collection

Weight: 26 kgAverage weight. Easy to install

Classification: CLASS A. Highest quality. Warranty

Temperature ratings (example). The temperature coefficient of a solar panel describes its response to different climatic conditions and seasonal changes. These ratings allow us to predict how the device will perform in the Uzbek climate - from the cold days of winter to the scorching heat of summer.

Temperature parameter table

Parameter	Value
Nominal operating temperature	45 ± 2°C
Power temperature coefficient	-0.40 %/°C
Average temperature coefficient	-0.31 %/°C
Minimum temperature coefficient	0.051 %/°C

What does it mean?

A temperature coefficient of -0.40 %/°C means that for every 1°C increase in panel temperature, power output decreases by 0.40%. For example, if the temperature increases from 25°C to 45°C, power can decrease by about 8%.

The nominal operating temperature of 45 ± 2°C is the typical outdoor operating temperature of the panel. This is important when choosing an installation location and determining the need for shading.

Safety and warranty: The solar panels used in the Smart Stop device fully comply with international safety standards. The manufacturer takes great responsibility for its products and provides a long-term warranty - which ensures the safety of your investment.

- 12-year product warranty: The manufacturer is responsible for all physical and technical defects of the panel for 12 years. This period is twice as long as the standard warranty period in the industry.
- 25-year linear power warranty: The panel is guaranteed to maintain the minimum power level specified by the manufacturer for 25 years. This allows for long-term economic planning.
- System safety: The maximum system voltage is 1500 V DC (IEC standard), which ensures safe operation even in high-voltage systems.
- Environmental safety: The device is completely safe for humans and pets. No harmful chemicals are used, and electromagnetic radiation is within the norm.

Discussion

Similar products and alternatives: There are various solar energy solutions on the Uzbek market that can be used in conjunction with the Smart Stop device or considered as an alternative. Each solution has its own advantages and areas of application, and the optimal option is selected depending on the project requirements.

1. Panels with different power ratings: 150 W, 540 W, 550 W and other power ratings. Each power rating meets different needs.

2. Complete solutions: 1 kW ready-made solar power plant kits. Delivered ready for installation.

3. Installation services: Professional installation, adjustment and commissioning services by a specialist. Provided with a warranty.

4. Batteries: High-capacity modern batteries for energy storage. An integral part of the Smart Stop system.

Future Development Prospects: Solar energy technologies are rapidly developing, and the Smart Stop device is expected to fully benefit from this development. A number of significant changes and expansions are expected in the coming years.

1. Energy storage: Improvements in solid-state batteries and high-capacity battery technology. The operating time on a single charge will be significantly extended.

2. Transport integration: Widespread use at public transport stations — bus, tram, metro — and the addition of electric vehicle charging capabilities.

3. Smart cities: Integration of Smart Stop devices into IoT systems, city monitoring centers, and smart management systems.

Advantages of "Smart Stop - Solar Panel Seat". The Smart Stop device sets a new standard for modern urban infrastructure. It combines functionality, aesthetics, environmental responsibility and technological innovation at the same time.

Convenience

The ability to charge mobile devices at any public place, anytime. A constant source of energy for users.

Savings

Use free and renewable solar energy. No dependence on the electricity grid - minimal utility costs.

Ecological Cleanliness

Does not cause any harm to the environment. Reducing carbon footprint and supporting the green city concept.

Innovative Solution

Current and promising technology for modern cities. A current practical demonstration of the infrastructure of the future.

FUser reviews and ratings. The true value of any innovative product is revealed when it is tested by users in real life. User reviews and ratings of the Smart Stop device are an important source for further product improvement. "Being able to charge my smartphone in public places is an integral part of living in a modern city. Smart Stop fills this gap."

Convenience rating: Users highly appreciate the ease of installation and aesthetic appearance of the device. Convenient location of USB ports and sufficiently long cables are important factors.

Efficiency rating: On sunny days, the charging speed is comparable to a standard wall outlet. On cloudy days, there is backup power from the battery.

Overall impression: Currently, as a new product on the market, extensive user reviews are in the process of formation. Initial tests show positive results.

Smart-market.uz is one of the leading companies in the solar energy solutions market in Uzbekistan and has implemented more than a thousand successful projects.

Conclusion

The energy of the future is with you today. Smart Stop – A solar bench is not just a place to sit — it is a modern embodiment of future technologies. Each installed device modernizes the urban landscape, makes the daily life of citizens more convenient and demonstrates our responsibility to nature. Solar energy is one of the great discoveries of mankind, and its integration with public infrastructure is a new paradigm of modern city management. Smart Stop is a practical, tangible and everyday expression of this paradigm. It turns a simple metal bench in parks and alleys into an energy center, allowing every passerby to taste the fruits of technological progress.

Today	Tomorrow	Future
Solar panels are being installed in city parks and citizens are using free charging services.	A Smart Stop network connected to IoT systems, monitored in real time, and integrated into a smart city network.	All public spaces have been converted to solar power, carbon neutrality has been achieved, and energy-independent cities have been created.

"The energy of the future is clean, free and available to everyone. Smart Stop is a step of the future into today."

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METHOD OF SOFTWARE SELECTION OF OBJECTS BASED ON INTEGRATION OF NAVIGATION DATA AND VISUAL FEATURES

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https://doi.org/10.5281/zenodo.20068133

Abstract. *This article presents the concept and mathematical implementation of an autonomous UAV control algorithm intended for high-precision positioning relative to an object at the final stage of a flight mission. A method for automatic identification of the object of interest is proposed, based on the joint processing of the UAV's current coordinates, the specified geographic coordinates of the object, and a real-time video stream.*

The main attention is paid to the mathematical model for extrapolating the calculated position of the object into the video-frame plane. The algorithm uses satellite navigation data to form a dynamic "region of interest" (ROI), within which software-based search and classification of objects are performed using computer vision methods. A selection mechanism is described that allows the system to automatically choose the target object from an array of detected targets by comparing their screen coordinates with the target coordinate of the object entered at the route-planning stage.

The developed software solution provides a transition from waypoint navigation to precise visual tracking of the object. Application of the proposed algorithm makes it possible to significantly increase the accuracy of autonomous maneuvering at the final section of the route, compensating for errors in navigation systems and eliminating the need for operator involvement or a stable communication channel.

Keywords*: visual navigation, machine vision, unmanned aerial vehicles, flight controller.*

INTRODUCTION

Relevance of the topic. The current stage in the development of unmanned aerial vehicles (UAVs) is characterized by a transition from remotely controlled platforms to fully autonomous systems capable of performing complex technological tasks under conditions where stable coverage of navigation and communication networks is unavailable. One of the key problems in carrying out flight missions at significant distances from the base station is the degradation of communication quality. Limitations in the power of receiving and transmitting devices, the curvature of the Earth's surface, and terrain features often make it impossible to maintain a stable video channel and command-control link on remote sections of the route.

Moreover, dependence on active communication systems reduces the autonomy and interference resistance of UAVs. Constant data exchange makes the system vulnerable to external electromagnetic interference and also allows third-party technical means to detect the location of the aircraft and its owner. In industrial monitoring or search-and-rescue operations, this can lead to loss of control due to industrial interference or deliberate distortion of GNSS signals (spoofing). In this regard, the concept of using UAVs that function solely on the basis of integrating satellite

and inertial navigation systems in a mode without active emission is a priority for ensuring the reliability and stability of the aircraft's operation.

Research problem. Despite their high autonomy, flights based exclusively on GNSS and INS systems have a critical drawback: accumulated positioning error at the final section of the route. The error of standard navigation receivers under real conditions can reach 15 meters, and INS systems are subject to temporal drift. Together, this creates a significant deviation from the calculated point, which does not allow effective performance of tasks that require precise interaction with small-sized objects, for example, targeted cargo delivery or detailed inspection of infrastructure elements.

The existing technological gap lies in the difficulty of ensuring high accuracy when reaching a specified point without the use of external correction. Traditional machine-vision algorithms are capable of detecting objects; however, in the absence of communication with an operator, they face the problem of erroneously selecting the target landmark when multiple similar objects are present in the work zone. A method is needed that will allow a UAV to independently perform intelligent object selection by matching visual data with the parameters embedded in the digital flight mission.

The purpose of this work is to develop an algorithm for autonomous selection and approach of a UAV to an object, which makes it possible to increase the accuracy of technological operations at the final section of the route through dynamic integration of GNSS navigation data and software analysis of the video image.

To achieve this purpose, the following tasks are addressed:

1. Development of a mathematical model for predicting the screen coordinates of the target landmark based on extrapolating data from the flight mission, namely the coordinates of the last route point, into the video-frame plane.

2. Description of an algorithm for the step-by-step transition from navigation by satellite coordinates to autonomous visual tracking of the object.

METHODS

The methodological basis of this work consists of a combination of theoretical modeling and analysis of data from a field experiment. The study applies the method of post-processing video data (post-flight analysis) obtained during a test flight of a flying-wing UAV.

To verify the proposed object-selection algorithm, a test scenario was designed and implemented, simulating the performance of a task in fully autonomous mode.

The logic of the proposed method is based on hierarchical filtering of visual data and includes the key stages of automating decision-making on board the UAV.

1. Initialization of the autonomous guidance phase

The software system switches to active mode when the penultimate navigation point embedded in the mission is reached. At this moment, a descent maneuver toward the target coordinate T(Lat_t, Lon_t) is initiated. This stage is critical for stabilizing the UAV motion vector in the direction of the object, which creates the necessary conditions for the correct projection of geographic coordinates onto the video-frame plane and for activation of the search algorithms.

2. Primary detection and software classification

During the approach, continuous analysis of the video stream is performed using computer-vision methods. The software searches for objects that correspond to a pre-established class, or preset, specified before the start of the mission, for example, "motor vehicle," "building," or "engineering object." At this stage, a dynamic array of candidates is formed, where each object is

characterized by its type and the screen coordinates of its center of mass in the relative coordinate system of the frame.

3. Spatial selection by motion vector

To minimize computational load and eliminate false detections, a method of selection according to the direction of the path vector is applied. Using inertial-system data on the current heading and pitch angle, as well as the current UAV coordinates C(Lat_c, Lon_c) and target coordinates T(Lat_t, Lon_t), the algorithm determines the calculated direction of the aircraft's movement in the GPS-coordinate plane and in the image plane.

Filtering logic: Initially, the algorithm calculates the azimuth angle of the direction toward the target using formulas of spherical trigonometry, using the current GPS coordinates of the UAV C(Lat_c, Lon_c) and the mission target coordinates T(Lat_t, Lon_t). The difference between the current heading of the aircraft and the calculated target azimuth determines the required heading deviation.

A linked coordinate system is constructed on the video-image plane, where the center of the frame is taken as the origin. The y-axis corresponds to the pitch angle, or vertical component, while the x-axis corresponds to yaw or heading deviation, the horizontal component.

Object rejection algorithm:

Having calculated the motion vector toward the target in space, the software system projects it onto the frame plane. This makes it possible to divide the entire visible space into a "target sector" and "rejection zones."

Direction criterion: If the calculated motion vector indicates the presence of the target in a certain quadrant, for example, to the lower right relative to the current optical axis, then all objects located in the opposite quadrants are automatically assigned the status of "low priority." In Figure 2, if the motion vector is directed toward objects 2 and 3, object 1, located at a significant distance along the x-axis (heading deviation) and y-axis, will be rejected by the algorithm as not corresponding to the approach trajectory.

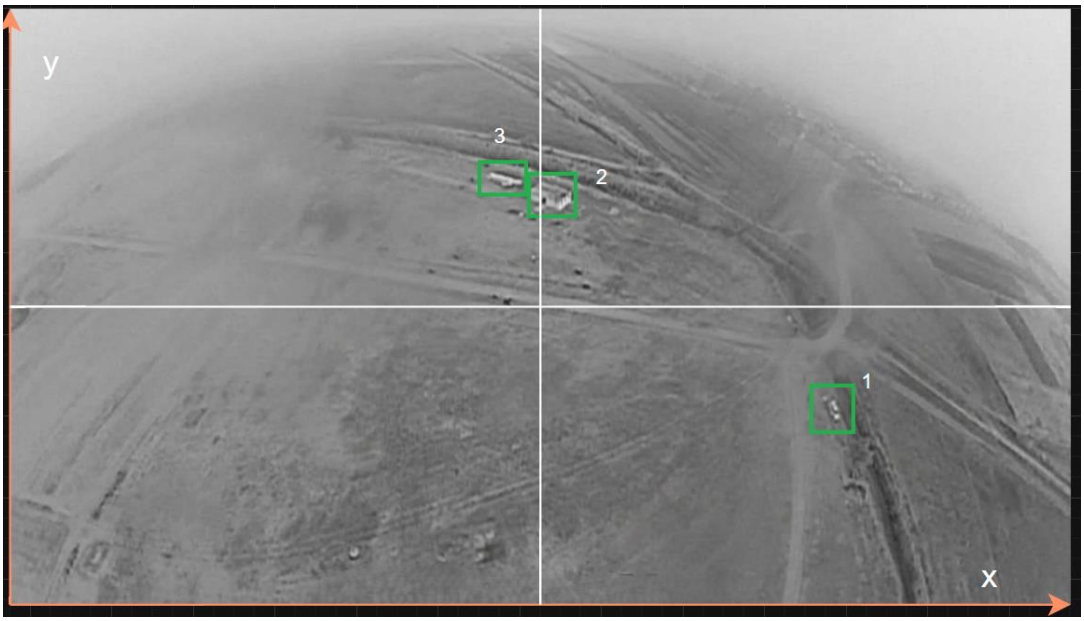


Figure 2. Process of software object selection in the video stream. The overlay of the coordinate grid (x — heading deviation, y — pitch) makes it possible to compare the position of detected objects 1, 2, and 3 with the calculated GPS motion vector.

After the primary rejection of objects that do not correspond to the motion vector, the software system proceeds to the stage of coordinate selection of the remaining candidates, in the example under consideration, objects 2 and 3. The task of this stage is to determine which of the detected targets is closest to the true geographic coordinates of the target T(Lat_t, Lon_t) specified in the flight mission.

Mathematical prediction of object coordinates

Initially, the angular deviations of the object center of mass (α_i, β_i) relative to the optical axis are determined. Taking into account the focal length of the lens f and the position of the object on the frame coordinate grid (x_i, y_i), the angles are calculated as follows:

$\alpha_i = \arctan(x_i / f);$

$\beta_i = \arctan(y_i / f);$

Here, x_i and y_i are the displacement of the object from the frame center in pixels, converted to metric units through the pixel size of the sensor matrix.

At the moment of task execution, the UAV is in the dive phase at an angle θ. With a known flight altitude H, obtained from barometric or inertial sensor data, the horizontal distance L_i, or projection onto the Earth's surface, to the object is calculated by the formula:

$L_i = H / \tan(\theta + \beta_i)$

This formula is valid on the condition that the camera is rigidly fixed parallel to the longitudinal axis of the aircraft. If the camera has an inclination angle, it is added to the current pitch angle.

Having the distance to the object L_i and its azimuth direction $Az_i = \varphi + \alpha_i$, where φ is the current heading of the UAV, the increments of latitude ΔLat_i and longitude ΔLon_i can be calculated. In view of the small distances on the final section (up to 500–1000 m), use of the flat-Earth model is acceptable:

$\Delta Lat_i = (L_i * \cos(Az_i)) / R;$

$\Delta Lon_i = (L_i * \sin(Az_i)) / (R * \cos(Lat_c));$

where R is the mean radius of the Earth.

Final calculated coordinates of the object:

$Lat_i = Lat_c + (\Delta Lat_i * 180) / \pi;$

$Lon_i = Lon_c + (\Delta Lon_i * 180) / \pi;$

Decision-making algorithm

At the final stage of selection, the predicted coordinates of each object are compared with the reference target coordinate from the mission. The program calculates the magnitude of the error, or deviation, vector for each candidate. The priority target is selected according to the criterion of minimum spatial mismatch.

The final stage of the algorithm is the closing of UAV control on the visual features of the selected object. From the moment of unambiguous identification of the priority target, GPS/INS navigation data cease to be used as the primary information source. The system switches to automatic object-tracking mode, where the main task is to minimize the mismatch error between the center of the video frame and the center of the selected object along both axes.

In real flight, this process is implemented as follows: at the beginning of the dive, Figure 3, when the target is still at a considerable distance, the algorithm continuously selects and verifies candidates. Once the selection is made, control commands are generated for the control surfaces of the flying wing, aimed at aligning the frame center with the target center. This provides high dynamic accuracy: on the final section of the trajectory, Figure 4, the UAV keeps the selected

object strictly in the center of the frame, which makes it possible to compensate for navigation-system error regardless of accumulated GPS error.

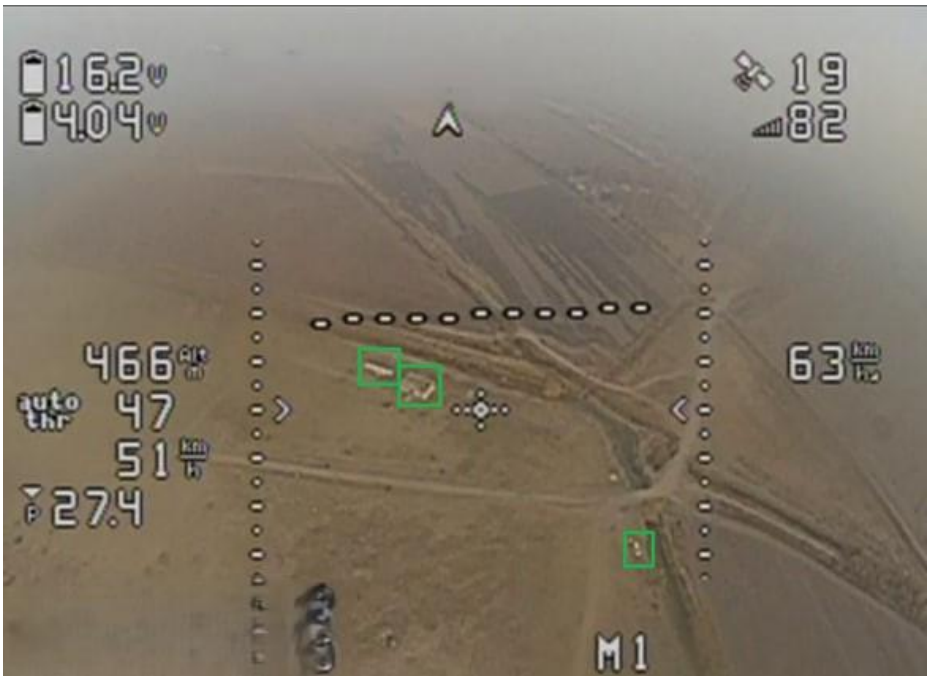


Figure 3. Stage of active object selection based on the video stream at the beginning of the approach maneuver.

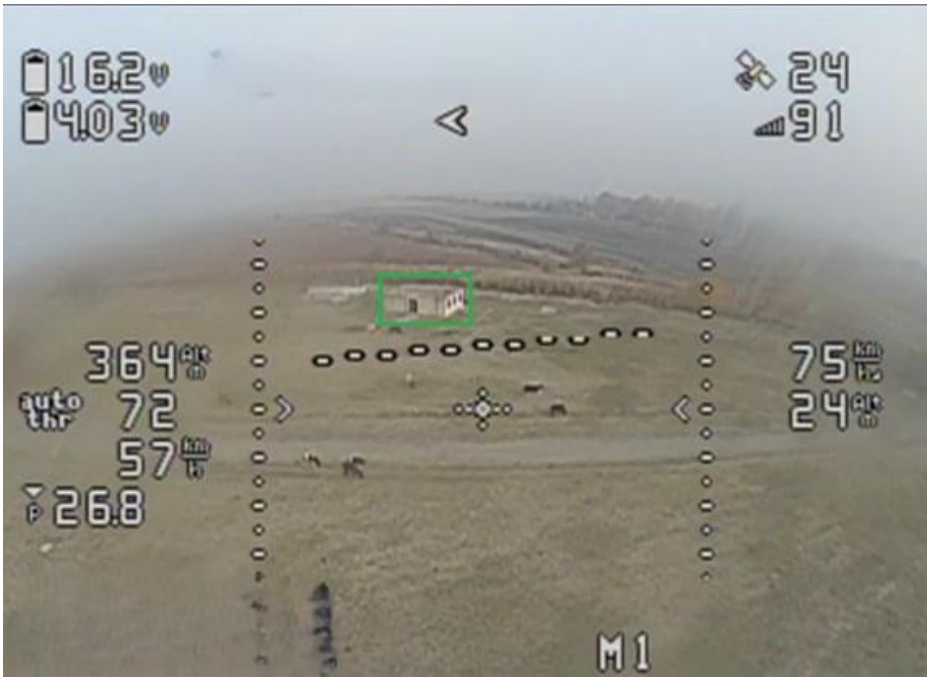


Figure 4. Stage of visual capture and holding of the object at the center of the frame after unambiguous identification by the onboard software.

CONCLUSION

In the course of the study, a concept of a software algorithm for autonomous object selection and precise UAV approach at the final section of the route was developed and mathematically substantiated. The proposed method makes it possible to effectively solve the problem of insufficient accuracy of navigation systems (GNSS/INS) and eliminate the need to maintain active communication channels, which is a determining factor for ensuring reliable

operation of the aircraft under conditions without external correction and in the presence of electromagnetic interference.

Based on the results obtained, the following conclusions were drawn:

• Improving positioning accuracy: The use of computer-vision methods for trajectory correction at the final stage made it possible to reduce the dynamic error from the calculated 15 meters typical of standard satellite navigation systems to minimum values comparable with the dimensions of the target object.

• Increasing autonomy and interference resistance: Implementation of the algorithm in a mode without active radio emission eliminates the UAV's dependence on external control channels, minimizing the risk of losing control of the aircraft due to industrial interference or distortion of GNSS signals.

• Intelligent landmark selection: The introduction of two-stage filtering — by path vector and subsequent coordinate verification — made it possible to automate the process of selecting the priority object among many similar visual landmarks. This ensures correct operation of the system in autonomous mode when navigating in zones with complex infrastructure.

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A DESIGN-SCIENCE METHODOLOGY FOR DEVELOPING AN AI-SUPPORTED ADAPTIVE SOFTWARE PLATFORM FOR METACOGNITIVE COMPETENCE IN HIGHER EDUCATION

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https://doi.org/10.5281/zenodo.21320392

Abstract. *Artificial intelligence (AI) can personalize learning, yet many platforms optimize content delivery without deliberately developing learners' ability to plan, monitor, evaluate, and regulate their learning. This design-science study proposes a methodology for an AI-supported adaptive platform centered on metacognitive competence. An integrative synthesis of 15 scholarly and policy sources was combined with design science research methodology to translate theory into platform requirements, architecture, adaptation rules, and safeguards. Sources were coded across five domains: metacognitive pedagogy, adaptive personalization, learning analytics and feedback, responsible AI governance, and software quality. The resulting artifact consists of eight interoperable modules: identity and consent, diagnostic assessment, an open learner model, a learning-object repository, an adaptation engine, metacognitive scaffolding, learner and instructor dashboards, and governance and audit services. Adaptation follows a cycle of diagnosis, goal setting, task selection, monitored performance, reflection, and model revision. Twenty-two design requirements and three use-case walkthroughs establish traceability between theoretical constructs and system functions. The methodology requires adaptation to preserve learner agency, explain recommendations, minimize data collection, and present AI outputs as contestable support rather than authoritative decisions. It provides a theoretically grounded blueprint for prototype development and later empirical validation in higher education across disciplines, institutional settings, and levels of study.*

Keywords*: artificial intelligence, adaptive learning, metacognitive competence, learning analytics, self-regulated learning, design science, higher education.*

Introduction

Artificial intelligence (AI) now forms part of many digital learning infrastructures. Contemporary systems can classify learner behavior, generate instructional explanations, recommend resources, automate selected assessment functions, and detect patterns associated with difficulty or disengagement. Reviews identify personalization, prediction, intelligent tutoring, assessment, and adaptive support as prominent applications of AI in education (Bond et al., 2024; Chen et al., 2020; Chiu et al., 2023). Universities have therefore begun to consider platforms that respond to differences in prior knowledge, pace, performance, and participation rather than presenting every learner with the same sequence.

Personalization, however, does not necessarily improve learning. An adaptive platform may choose each successive task while leaving the student unable to explain why it was selected, which strategy is appropriate, how progress should be judged, or when the approach should change. Such a system may improve short-term task completion while weakening the learner's responsibility for planning and regulation. This distinction matters in higher education, where

students are expected to become independent learners who can transfer strategies to unfamiliar problems, courses, and professional contexts.

Metacognition provides a theoretical basis for addressing this problem. Flavell (1979) defined it as knowledge about cognition together with the monitoring of cognitive activity. In education, the construct is commonly operationalized through goal setting, strategic planning, monitoring of comprehension and performance, evaluation of outcomes, and strategy revision. Zimmerman's (2002) cyclical account of self-regulated learning similarly connects forethought, performance control, and self-reflection. Panadero's (2017) comparison of self-regulated learning models shows that planning, monitoring, control, and reflection recur across theoretical traditions. A platform designed to develop metacognitive competence must therefore do more than infer which content a learner should receive; it must make regulatory choices visible and gradually transfer control to the learner.

Adaptive educational technology offers mechanisms for this purpose. Research on adaptive hypermedia established the value of maintaining a learner model and using it to modify content, navigation, presentation, or support (Brusilovsky, 2001). Studies of intelligent tutoring systems further show that the timing and granularity of interaction matter: step-level responses can provide support close to the point at which misconceptions or ineffective strategies emerge (VanLehn, 2011). Adaptation should therefore draw not only on answer accuracy but also on the learner's path, confidence, help-seeking behavior, revision history, and reflection.

Learning analytics can connect these behavioral traces to metacognitive support. Ferguson (2012) distinguished learning-focused analytics from broader institutional uses of data and emphasized the need to convert educational data into actionable understanding. Roll and Winne (2015) argued that analytics are particularly relevant to self-regulated learning because regulation unfolds over time and can be examined through sequences of decisions and actions. In an adaptive platform, dashboards and recommendations should therefore do more than display scores: they should help learners compare intentions with actions, recognize patterns, and choose a next step. Analytics should inform judgment rather than operate as a hidden mechanism that determines educational decisions without explanation.

Generative AI expands both the capabilities and the risks of adaptive systems. It can produce examples, questions, explanations, feedback, and reflective prompts at scale, yet fluent output may be inaccurate, biased, poorly aligned with the curriculum, or overly directive. AI literacy consequently forms part of metacognitive competence. Long and Magerko (2020) define AI literacy as competencies that enable people to evaluate, communicate with, and use AI critically. In a metacognition-centered platform, students should be able to inspect the basis of recommendations, question generated content, compare alternatives, and distinguish evidence from confident wording. The system should also communicate uncertainty and provenance instead of presenting generated output as unquestionably correct.

Policy guidance makes these design constraints explicit. The OECD (2021) notes the potential of smart technologies but also emphasizes institutional capacity, governance, and responsible use of educational data. Miao and Holmes (2023) recommend human-centered use of generative AI in education, including privacy protection, transparency, age-appropriate access, validation, and preservation of human agency. Recent evidence syntheses likewise call for more rigorous, ethically informed, and interdisciplinary AI-in-education research (Bond et al., 2024). A platform methodology should therefore integrate pedagogical, technical, and governance requirements from the beginning rather than treat ethics as a final compliance step.

The original multilingual manuscript proposed an AI-based adaptive platform for developing university students' metacognitive competence. Because it did not include the detailed data, instruments, or statistical outputs required to verify its empirical claims independently, the present article reframes the contribution as a design-and-development study. It does not claim that a completed platform has improved student outcomes. Instead, it specifies a theoretically grounded and auditable methodology for prototype construction and subsequent empirical testing.

The study addresses three research questions: (a) What pedagogical, analytical, technological, and governance requirements should guide the development of an AI-supported adaptive platform for metacognitive competence? (b) How can those requirements be represented in a coherent modular architecture and adaptation cycle? (c) Which analytical checks can be completed before a prototype is tested with students? Together, these questions connect metacognitive theory, adaptive learning, learning analytics, responsible AI, and software design within a single development methodology.

Method

Research Design

Design science research was used to create and evaluate a purposeful artifact that addresses an identified problem. In information systems research, an artifact may take the form of a construct, model, method, or instantiation when its design is grounded in a relevant problem and evaluated against explicit objectives (Hevner et al., 2004). The study followed the design science research methodology proposed by Peffers et al. (2007): problem identification, definition of solution objectives, design and development, demonstration, evaluation, and communication. The primary artifact is a development methodology expressed through design requirements, architecture, adaptation logic, safeguards, and a validation roadmap.

Evidence Base and Source Verification

The evidence base integrated foundational theory with contemporary AI-in-education practice. Fifteen sources published between 1979 and 2024 were selected because they addressed one or more of the following areas: metacognition and self-regulated learning; adaptive hypermedia and intelligent tutoring; learning analytics; AI in education and AI literacy; responsible technology policy; or design science methodology. Eligible materials included peer-reviewed journal articles, conference papers from established scholarly publishers, and reports issued by the OECD or UNESCO. Sources concerned solely with technical optimization and lacking an educational interpretation were excluded. Bibliographic metadata and DOI information were checked against publisher or issuing-organization records, and DOI links were included only when verified.

Coding and Requirement Derivation

Directed qualitative coding was used to analyze the evidence. Five domains were specified in advance because they corresponded to the components required for a usable platform methodology: metacognitive pedagogy, adaptive personalization, analytics and feedback, responsible AI governance, and software quality and interoperability. A source could contribute to more than one domain. During synthesis, theoretical propositions were translated into design implications. For example, the cyclical structure of self-regulated learning became a requirement for repeated goal setting, performance monitoring, reflection, and strategy revision rather than a single diagnostic event. The adaptive learner model likewise became a set of requirements for continuous updating, inspectability, and learner correction.

Each requirement had to satisfy four conditions: it had to state a pedagogical or operational purpose rather than merely name a technology; be implementable as a platform function, data rule, interface behavior, or governance control; remain traceable to at least one theoretical or policy source; and be assessable during prototype evaluation. Applying these conditions produced 22 primary design requirements across the five domains. Each requirement was then assigned to one or more architectural modules and to a stage of the adaptation cycle.

Artifact Construction and Adaptation Logic

The architecture was specified as a modular, service-oriented model that limits coupling between pedagogical functions and particular AI models. A university could therefore replace a recommendation algorithm or generative model without redesigning the entire environment. Eight modules were defined: identity and consent; diagnostic assessment; an open learner model; a learning-object and task repository; an adaptation and recommendation engine; a metacognitive scaffolding service; learner and instructor dashboards; and governance, audit, security, and interoperability services. The model assumes integration with an institutional learning management system through standard authentication and data interfaces but does not require a specific vendor.

The adaptation logic was formulated as a constrained decision process. The platform collects only data justified by defined learning purposes, updates the learner model, calculates a limited set of interpretable indicators, and proposes an action. Possible actions include adjusting task difficulty, recommending a strategy, prompting reflection, offering a worked example, or alerting an instructor. Curriculum alignment, accessibility, privacy permissions, and instructor-defined boundaries constrain every recommendation. Autonomous AI control is excluded from high-stakes decisions such as final grades or disciplinary judgments.

Analytic Evaluation and Ethical Scope

Before empirical testing, the artifact underwent two forms of analytical evaluation. First, a requirement-to-component traceability check examined whether each requirement was linked to a source, a platform module, an observable system behavior, and a future test criterion. Second, three use-case walkthroughs were completed: a learner who begins tasks without planning, a learner whose confidence is poorly calibrated to performance, and a learner whose repeated errors suggest strategic difficulty. Each walkthrough followed the full cycle from data capture and recommendation to learner response, reflection, and model revision. The analysis sought missing functions, unsafe assumptions, and points at which the platform might replace rather than support learner agency.

This conceptual design phase involved no human participants, personal data, or experimental outcome measures; institutional ethics approval was therefore not required. Any subsequent study involving students should obtain ethics approval, informed consent, data-protection review, accessibility testing, and a preregistered analysis plan. The present results are design propositions supported by theory, not evidence of educational effectiveness.

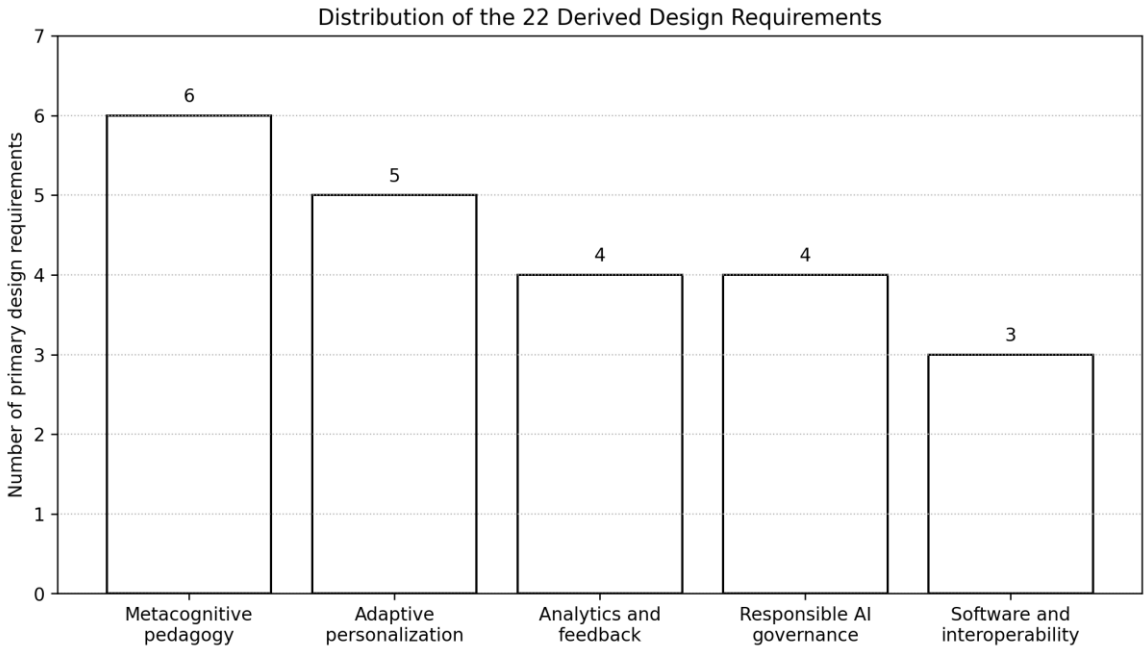
Results

Derived Design Requirements

The synthesis produced 22 primary requirements: six for metacognitive pedagogy, five for adaptive personalization, four for analytics and feedback, four for responsible AI governance, and three for software quality and interoperability. Figure 1 displays this distribution. The counts describe the structure of the proposed methodology and do not estimate effect size or importance. Metacognitive pedagogy received the largest allocation because the central design problem is not

the absence of adaptation but the possibility that adaptation may occur without developing the learner's regulatory capacity.

Figure 1. Distribution of the 22 Derived Design Requirements



Note. Requirements were assigned to one primary domain for display. The counts describe the proposed design framework and are not estimates of educational effects.

The six metacognitive requirements specify explicit support for goal formulation, strategy selection, monitoring, confidence judgments, reflection, and revision. These processes must be represented as learner actions rather than inferred only in the background. Learners should be able to state a goal, select or accept a strategy, inspect evidence of progress, compare confidence with performance, and record a reason for changing their approach. Scaffolds should fade when performance and monitoring stabilize because permanent prompting can create dependence rather than competence.

The five adaptive-personalization requirements address the learner model, task selection, difficulty adjustment, timing of support, and learner control. Adaptation should use several indicators rather than a single score. A low score may reflect a knowledge gap, misunderstood instructions, weak planning, excessive task difficulty, or an ineffective strategy, and these conditions require different responses. The platform should therefore combine evidence from performance, task history, time patterns, help requests, confidence, and reflection while avoiding unsupported psychological inference. Learners and instructors must be able to inspect and correct the model.

The four analytics-and-feedback requirements state that analytics must be timely, interpretable, actionable, and appropriate to the user's role. A learner dashboard should answer three questions: What did I intend to do? What did I actually do? What is a reasonable next action? An instructor dashboard should aggregate patterns without exposing unnecessary personal detail and should distinguish a class-wide instructional issue from an individual difficulty. Alerts must show the evidence that triggered them and must not be presented as diagnoses.

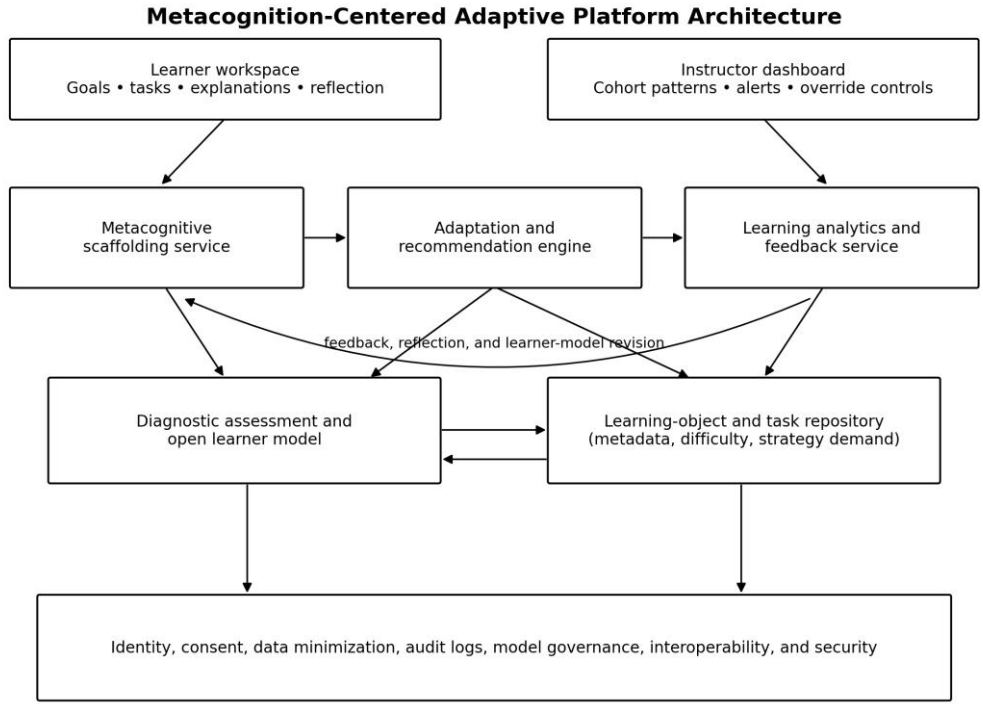
The governance requirements cover data minimization and consent, transparency and contestability, validation of AI-generated content, and human oversight. The software requirements address modularity, interoperability, reliability, and auditability. These provisions

are foundational: a pedagogically useful recommendation is still unacceptable if it relies on excessive data collection, cannot be explained, or cannot be reviewed after an error.

Platform Architecture

Figure 2 presents the proposed architecture. The interface layer separates learner and instructor views while allowing both groups to work with the same evidence base. The orchestration layer contains the metacognitive scaffolding service, adaptation engine, and analytics service. The core-model layer contains the diagnostic assessment and open learner model together with the repository of learning objects and tasks. A governance foundation supports identity, consent, security, audit logging, interoperability, and model management across all modules.

Figure 2 Metacognition-Centered Adaptive Platform Architecture



Note. Arrows represent the movement of evidence, recommendations, feedback, and learner-model updates. Governance and audit services apply across all layers.

The open learner model is central to the architecture. It stores current estimates of domain knowledge, strategy use, confidence calibration, goal progress, and support history. Here, open means visible and contestable: students can inspect selected indicators, add contextual information, and challenge an inaccurate inference. Instructors can review the evidence and override recommendations. This arrangement differs from a hidden profile that silently determines which resources a learner may access.

The learning-object repository requires pedagogically meaningful metadata. Beyond topic and difficulty, each item should be tagged for prerequisite knowledge, expected time, modality, accessibility features, cognitive demand, metacognitive demand, feedback type, and source provenance. Generative AI may create variants, hints, or explanations, but generated material should undergo automated checks and, for assessed or high-impact content, human review before release. The adaptation engine should prefer verified repository content when the confidence or provenance of generated output is insufficient.

The metacognitive scaffolding service converts platform evidence into prompts and tools. Before a task, it may ask the learner to set a goal, anticipate difficulty, or choose a strategy. During performance, it may insert a pause point, confidence check, or strategy reminder. After performance, it may compare anticipated and observed difficulty, invite error analysis, and request a decision about the next step. Because the prompts are tied to the task, they function as regulatory support rather than generic study advice.

Table 1 summarizes the modules, functions, metacognitive targets, and principal safeguards. Although the modules are separable for engineering purposes, they operate as an integrated cycle. The adaptation engine, for example, cannot recommend a task responsibly without repository metadata, learner-model evidence, and governance constraints; likewise, a dashboard cannot support reflection when its indicators are difficult to interpret.

Table 1

Functional Modules of the Proposed Adaptive Platform

Module	**Primary functions**	**Metacognitive target**	**Principal safeguard**
Identity and consent	Authentication, roles, consent records, permission management, and purpose limitation.	Agency and informed participation	Collect only necessary data; allow withdrawal and role-based access.
Diagnostic assessment	Prerequisite checks, initial strategy prompts, confidence ratings, and accessibility preferences.	Awareness of knowledge and strategy state	Use low-stakes evidence; avoid unsupported psychological labels.
Open learner model	Stores and updates knowledge, strategy, confidence-calibration, goal, and support indicators.	Monitoring and self-knowledge	Learner inspection, correction, explanation, and instructor override.
Learning-object repository	Curated tasks, resources, worked examples, metadata, provenance, and accessibility features.	Strategic choice and task understanding	Curriculum alignment; review generated high-impact content.
Adaptation engine	Ranks eligible tasks and supports using interpretable indicators and constraints.	Planning, control, and strategy revision	Explain recommendations; never automate final high-stakes decisions.
Metacognitive scaffolding	Goal prompts, strategy menus, pause points, confidence checks, reflection, and fading support.	Planning, monitoring, evaluation, and regulation	Avoid excessive prompting; adapt support intensity and permit refusal.

Module	Primary functions	Metacognitive target	Principal safeguard
Learner and instructor dashboards	Displays progress, intention-action comparisons, alerts, and evidence for next steps.	Reflection and informed decision making	Role-sensitive views; no diagnostic language or opaque risk scores.
Governance, audit, and interoperability	Security, audit logs, model versioning, content provenance, APIs, and reliability controls.	Trustworthy participation in AI-supported learning	Data minimization, human oversight, incident review, and system portability.

Note. The modules are logically separable but operate as a single adaptation and reflection cycle.

Adaptation Cycle and Analytic Walkthroughs

The adaptation cycle comprises six stages. Diagnosis first establishes a provisional profile from prerequisite checks, brief metacognitive prompts, and available course history. Goal setting then records the learner's intended outcome, time horizon, and selected strategy. Task selection ranks eligible activities according to curriculum fit, estimated challenge, accessibility, prior support, and the learner's stated goal. During monitored performance, the platform records task-relevant traces such as attempts, hint use, revisions, response-time ranges, and confidence ratings. Reflection compares intention, action, outcome, and confidence. Finally, model revision updates only indicators supported by evidence and presents an explained recommendation for the next step.

Recommendation ranking must remain interpretable. The proposed engine calculates priority from four components: knowledge need, strategy need, confidence-calibration need, and engagement risk. Each component is normalized and weighted through instructor-configurable parameters. A task is eligible only when it satisfies curriculum, accessibility, privacy, and prerequisite constraints. The learner then receives a concise rationale, such as: "This task is recommended because two prerequisite items were missed, confidence was high despite incorrect answers, and a worked-example strategy has not yet been tried." Such explanations make recommendations inspectable and turn adaptation into an opportunity for metacognitive judgment.

The first walkthrough examined a learner who repeatedly begins complex tasks without planning. The platform detects no recorded goal or strategy selection and observes rapid task entry followed by frequent restarts. Instead of immediately lowering the difficulty, it asks the learner to state the task goal, select a strategy from a short list, and estimate the required time. If performance improves, the planning prompt gradually fades. If the pattern persists, the system sends the instructor an alert supported by the observed sequence. Rapid entry is not treated as a psychological deficit, and the learner can explain contextual factors.

The second walkthrough addressed confidence calibration. A learner reports high confidence but repeatedly answers incorrectly. The platform displays the mismatch, asks what evidence supported the confidence judgment, and recommends a verification strategy such as self-explanation or comparison with a worked example. Later tasks request another confidence rating

so that the learner can assess whether the judgments are becoming better calibrated. The aim is to improve monitoring accuracy, not to discourage confidence.

The third walkthrough addressed repeated strategic difficulty. A learner spends substantial time, uses many hints, and makes the same type of error across related tasks. The system proposes an alternative representation or strategy and explains the reason. If the learner rejects the recommendation, the choice is recorded and another option may be selected. The instructor dashboard displays the recurring pattern, the supports already offered, and the learner's responses. The platform does not escalate the case autonomously; it provides evidence for a human decision.

The traceability check linked all 22 requirements to at least one source, one module, one observable behavior, and one future test criterion. The walkthroughs also identified three cross-cutting controls that were added to the methodology: a visible explanation for every consequential recommendation, an override mechanism for learners and instructors, and a provenance flag for generated content. These checks support the internal completeness of the design, but they do not establish usability, learning gains, or causal impact. Those outcomes require empirical evaluation of a working prototype.

Discussion

Educational personalization often adapts the environment while leaving the learner's regulatory activity implicit. The proposed methodology addresses this weakness by organizing adaptation around diagnosis, goal setting, task selection, monitoring, reflection, and revision. Metacognition is treated both as a learning outcome and as a process through which learning occurs. This arrangement is consistent with Flavell's (1979) distinction between metacognitive knowledge and monitoring, Zimmerman's (2002) cyclical model, and the common regulatory functions identified across self-regulated learning models (Panadero, 2017). The platform is intended to help students understand and eventually manage decisions that the system initially supports.

The architecture extends established adaptive-hypermedia principles. Brusilovsky (2001) emphasized learner modeling and adaptive presentation or navigation, whereas current AI systems can use a wider range of data and generate content dynamically. Greater capability increases the need for constraints. The model therefore limits adaptation to curriculum-aligned options, requires explanations, and preserves learner and instructor override. It also uses step-level evidence when appropriate, consistent with VanLehn's (2011) conclusion that interaction granularity shapes what a tutoring system can diagnose and support.

Learning analytics serves a pedagogical rather than merely predictive function in this model. Ferguson (2012) noted that analytics can serve distinct institutional and educational purposes, while Roll and Winne (2015) emphasized the value of traces for examining regulation over time. The proposed dashboards therefore prioritize comparison, interpretation, and action. A prediction may indicate possible risk, but it does not establish a cause. Explanations and contextual input remain necessary because the same trace pattern may arise from different circumstances.

AI literacy is also treated as an operational platform requirement. Students should learn to interrogate AI-generated feedback rather than simply receive it. Long and Magerko's (2020) competency framework supports features such as provenance displays, uncertainty statements, output comparison, and opportunities to challenge recommendations. These functions are particularly important for generative AI, whose fluency can conceal factual or pedagogical weaknesses. The platform should make critical use easier than passive acceptance.

Responsible design is integral to educational quality. Miao and Holmes (2023) and the OECD (2021) emphasize human-centered governance, privacy, institutional readiness, and appropriate oversight. The methodology translates these principles into purpose limitation, consent, minimal data collection, role-based access, audit logs, model review, content provenance, and a prohibition on autonomous high-stakes decisions. These controls also respond to evidence syntheses calling for greater ethical rigor and stronger educational involvement in AI-in-education research (Bond et al., 2024; Chiu et al., 2023).

For developers, the main implication is methodological: an adaptive platform should begin with pedagogical objectives and observable learner decisions, not with an AI model in search of an application. Designers can then identify the minimum data and computational functions required to support those objectives. The modular architecture permits the use of rules, classical machine learning, generative AI, or combinations of these methods. A sophisticated model is unnecessary for every function; transparent rules may be preferable when the educational logic is stable and the decision has substantial consequences.

The design assigns shared control to teachers and students. Instructors define curriculum boundaries, approve high-impact content, configure alert thresholds, and interpret patterns in context. The platform may reduce routine monitoring but does not replace pedagogical judgment. Students can inspect goals, evidence, recommendations, and learner-model assumptions, and they may reject or revise a recommendation. This distribution of control is necessary when the intended outcome is autonomy rather than compliance.

Several limitations remain. The source set was purposively constructed and does not constitute a systematic review of all relevant literature. The counts in Figure 1 describe the design framework rather than bibliometric prevalence. Because the architecture has not been implemented, the walkthroughs cannot reveal usability problems, accessibility barriers, institutional constraints, or unintended behavior that may emerge in practice. The study also does not validate an instrument for measuring metacognitive competence. Technical choices, including model type, data schema, and interoperability standards, will depend on the institutional environment.

Validation should proceed in stages. Participatory design should first involve students, teachers, accessibility specialists, data-protection staff, and software engineers. A low-risk prototype should then be tested for usability, comprehension of explanations, learner-model accuracy, and recommendation appropriateness. A preregistered pilot can subsequently examine process measures such as goal quality, strategy use, confidence calibration, reflection quality, and help-seeking. Only after these checks should a controlled study estimate effects on learning and metacognitive competence. Longitudinal follow-up is needed to determine whether students transfer regulatory strategies beyond the platform.

Conclusion

This paper presents a design-science methodology for an AI-supported adaptive software platform intended to strengthen metacognitive competence. The methodology integrates metacognitive and self-regulated learning theory, adaptive learning, learning analytics, AI literacy, responsible AI governance, and modular software design. It connects theory to implementable platform functions through 22 requirements, eight modules, a six-stage adaptation cycle, explainable recommendation logic, and safeguards for agency, privacy, oversight, and content validity.

The artifact is a blueprint rather than evidence of effectiveness. It avoids unsupported experimental claims and identifies the empirical work still required. A platform based on this methodology will be educationally defensible only when students can understand and contest its recommendations, teachers retain meaningful control, data use remains proportionate, and adaptation gradually increases learner independence. Under these conditions, AI can serve not merely as an automated content selector but as structured support for learning how to learn.

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DIGITAL DECISION SUPPORT FOR SCIENTIFIC-TECHNICAL COUNCILS AND MINISTRY-LEVEL REVIEW IN STATE RESEARCH PROGRAM MANAGEMENT

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Abstract. *In state research programs, the scientific-technical council (STC) and the ministry-level council are the points at which expert assessments become binding administrative decisions. Subsequent contracting, financing, and monitoring depend on both the recorded decision and the quality of its supporting evidence. This paper presents a decision-support design for this stage of program governance. The review dossier is modelled as a versioned information object, and the council procedure is represented as a guarded state machine in which transitions are permitted only when the required evidence is present. The design combines four components: explicit preconditions for quorum, ballot tallies, and decision rationales; a sealed-ballot mechanism that preserves the confidentiality of individual votes while allowing independent tally verification; automated protocol generation conditional on complete session evidence; and a hash-chained audit record with periodic external anchoring to reveal retroactive alteration. The paper further defines council-stage performance metrics, including concordance between STC and ministry-level decisions, together with their data sources and measurement windows. The design does not assume that digitalization improves expert judgment; it aims instead to make council procedures reproducible, auditable, and comparable across program cycles.*

Keywords: *decision support systems, scientific-technical councils, sealed voting, automated minutes, tamper-evident audit logs, research program administration*

Introduction

Scientific-technical councils in state research programs operate under a distinctive administrative constraint: they exercise collegial authority through records that are often finalized only after the meeting. Agendas may be circulated by email, dossiers may contain files whose versions have not been formally fixed, votes may be taken by a show of hands, and minutes may later be reconstructed from a secretary's notes. Although each practice may be manageable in isolation, their combination makes subsequent verification difficult. An auditor reviewing a decision many months later may be unable to determine precisely which materials the council considered or how the recorded outcome was calculated.

Three recurring failure modes motivate the proposed design. First, version drift can occur when the council reviews one file while a different version is later attached to the contract, with no hash or timestamp to resolve the discrepancy. Second, voting rules may be applied inconsistently, especially when regulations do not clearly operationalize the treatment of abstentions. Third, decision records may capture the outcome without sufficient procedural context, preventing later reviewers from verifying quorum, attendance, or the rationale for a negative or conditional decision.

These problems require more than digitized forms. They require explicit constraints on the sequence in which information objects can change state and a record of each change that can be independently verified. Accordingly, the council is modeled not simply as a software user but as the authorized body that triggers guarded transitions within a controlled decision process.

This paper contributes a formal model of a two-tier council procedure based on a versioned dossier, explicit guards for quorum, expert-score dispersion, and evidence completeness; a sealed-ballot design that separates participation records from ballot content; a protocol-generation rule that prevents incomplete decision records; and a measurement framework for evaluating the council stage. Together, these elements address procedural traceability without transferring decision authority to an algorithm.

The proposed system does not rank projects or recommend outcomes. Its function is limited to preserving the materials considered by the council, enforcing procedural preconditions, recording the decision process, and maintaining an auditable evidentiary chain. Decision authority remains with the councils.

Background and Related Work

Decision support has long been framed around the stages of intelligence, design, and choice (Simon, 1960), while classical decision-support architectures distinguish data, model, and dialogue components (Bonczek et al., 1981). Later work described the incorporation of web technologies and data warehousing into these architectures (Shim et al., 2002). The present study is most closely aligned with group decision support, in which the unit of analysis is a deliberative body operating under procedural rules rather than an individual analyst (DeSanctis & Gallupe, 1987). Early field studies of electronic meeting systems further showed that anonymous input can affect the substance of group discussion as well as its efficiency (Nunamaker et al., 1991).

Research on peer review also supports the use of dispersion controls before council deliberation. Studies of grant and manuscript review have reported limited agreement among independent reviewers, while broader analyses attribute this variability to structural features of expert judgment (Bornmann, 2011; Cicchetti, 1991; Marsh et al., 2008). Kahneman et al. (2021) distinguish unexplained variability, or noise, from systematic bias and argue that it should be measured directly. For council review, reporting only a mean score can therefore conceal disagreement that may be substantively important.

Voting rules likewise affect outcomes and should not be treated as implementation details. Arrow (1951) demonstrated fundamental limitations in aggregating individual preferences, and comparative work on approval and threshold rules shows that different defensible procedures can produce different collective outcomes from the same preferences (Brams & Fishburn, 1978). Accordingly, the counting rule, including the treatment of abstentions, should be stored as a session parameter rather than determined after voting.

Business process management provides the language of guarded transitions and process conformance (Dumas et al., 2018), while process mining offers methods for comparing recorded behavior with a specified model (van der Aalst, 2016). BPMN provides a notation suitable for communicating such procedures to administrative users (Object Management Group, 2013). The integrity of process records can be strengthened through linked timestamping and forward-secure audit logs (Haber & Stornetta, 1991; Schneier & Kelsey, 1999), while records-management and information-security standards define requirements for evidentiary records and control environments (International Organization for Standardization, 2016; International Organization for Standardization & International Electrotechnical Commission, 2022). E-government research

also emphasizes vertical and horizontal integration across administrative levels (Layne & Lee, 2001), a requirement directly relevant to two-tier council review.

However, these literatures do not directly specify the administrative object examined here: a single dossier that passes through two councils of different rank while preserving a continuous evidentiary chain within the regulatory framework of a national research program. The proposed design addresses that gap without altering the councils' statutory decision authority (Law of the Republic of Uzbekistan on Science and Scientific Activity, 2019; Regulations on the Procedure for Organising and Financing State Scientific and Scientific-Technical Programmes of the Republic of Uzbekistan, n.d.).

Materials and Methods

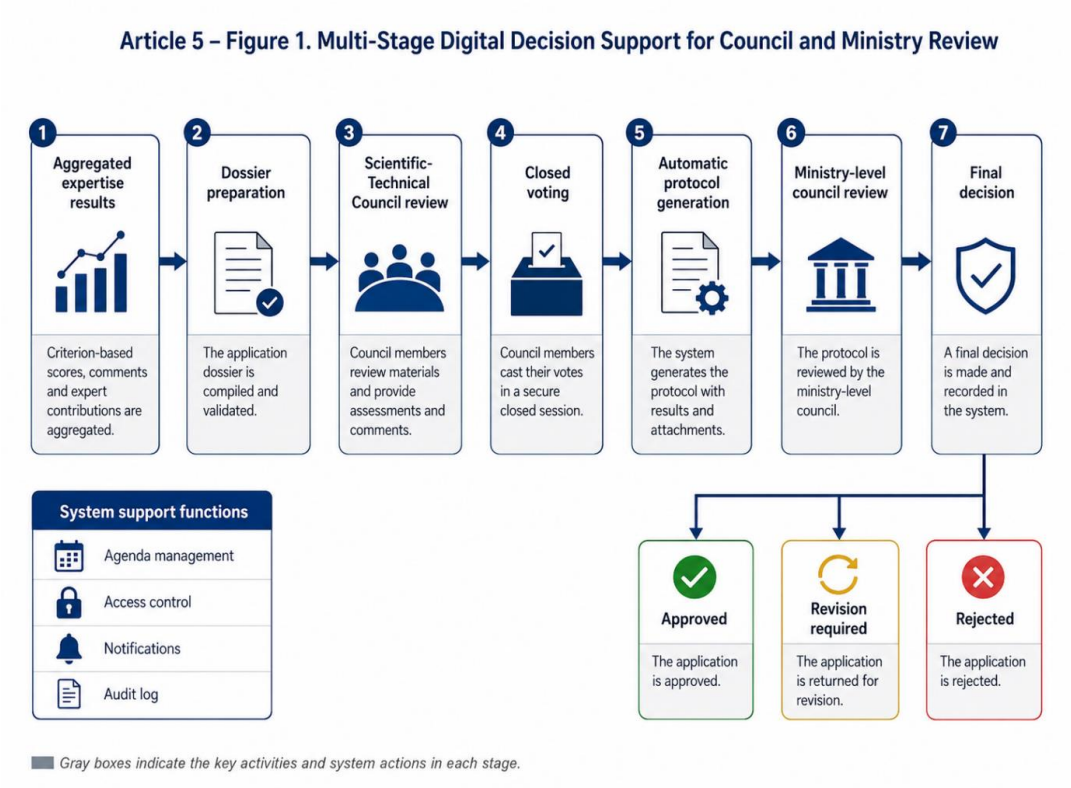
The model was derived from three source categories: the regulatory procedure governing project review in state scientific and innovation programs; the module structure of an operational platform for scientific and innovation activity management; and council-secretariat practices reflected in session materials. The analysis identified the actors, information objects, and events that move a project across administrative stages. These elements were then specified as a state machine, with each reachable state assigned a predecessor and an explicit entry guard. The regulatory component was based on the applicable national law and program-financing procedure (Law of the Republic of Uzbekistan on Science and Scientific Activity, 2019; Regulations on the Procedure for Organising and Financing State Scientific and Scientific-Technical Programmes of the Republic of Uzbekistan, n.d.).

Six roles are represented. The secretary assembles the dossier, prepares the agenda, and opens the session. Council members review materials and cast ballots. The chair opens and closes voting and signs the protocol. The ministry-level reviewer receives the protocol and dossier and records one of the permitted review outcomes. The applicant can view status information and, for negative or conditional decisions, the stated rationale. The auditor has read-only access to the complete evidentiary chain and no write access. This separation should be enforced through database privileges rather than only through the user interface.

The principal information objects are the project dossier, its associated expertise records, the session record, the ballot set, the protocol, and the audit chain. Each object is versioned by content hash, so a protocol reference resolves to a specific byte sequence rather than only to a filename. Figures 1 and 2 summarize the resulting process chain and module architecture.

Figure 1

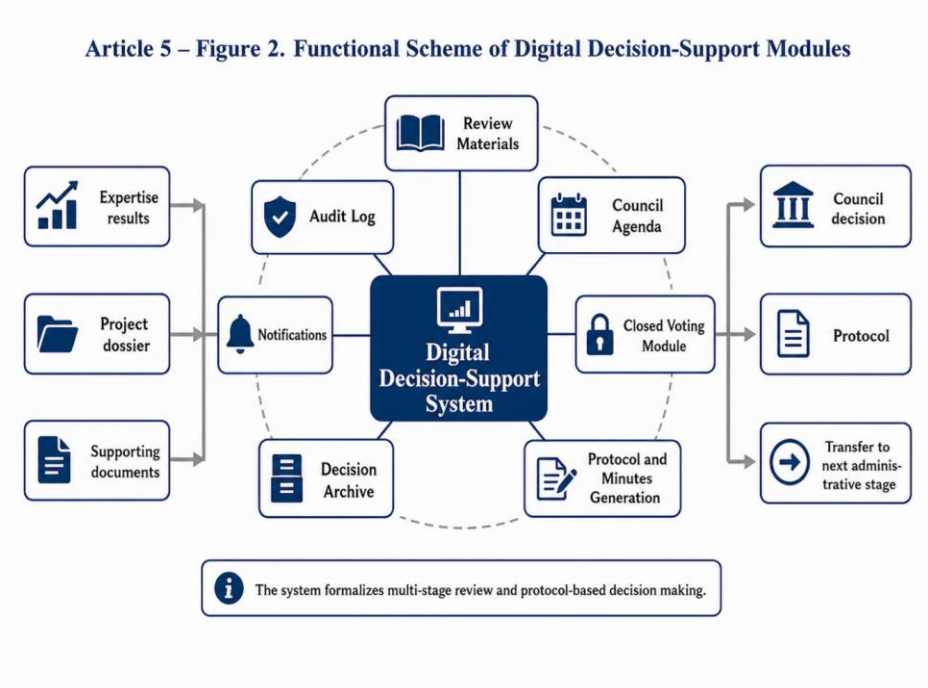
Multi-Stage Digital Decision Support for Council and Ministry-Level Review



Note. The workflow moves from aggregated expertise results through dossier preparation, STC review, closed voting, protocol generation, ministry-level review, and the recorded final decision.

Figure 2

Functional Scheme of the Decision-Support Modules



Note. Inputs are shown on the left, operational modules surround the core service, and administrative outputs are shown on the right.

Formal Model

Dossier and Expertise Aggregation

A dossier is a tuple

$$D = \langle id, A, E, V, \sigma, H \rangle$$

where id identifies the project; A contains applicant and project metadata; E is the set of expertise records; V is the set of document versions and corresponding content hashes; $\sigma \in \Sigma$ denotes the current procedural state; and H denotes the dossier's audit chain.

Each expertise record $e_j \in E$ contains a criterion vector $s_j = (s_{j1}, \ldots, s_{jn})$, a free-text justification, and a timestamp. Given criterion weights $w = (w_1, \ldots, w_n)$, with $\Sigma w_k = 1$, the weighted total for expert j and the aggregate across m experts are

$$s_j = \Sigma_k w_k \cdot s_{jk} \qquad S = (1/m) \cdot \Sigma_j s_j$$

The aggregate score alone is not sufficient for council review. The model therefore calculates the dispersion of expert totals:

$$R = \max_j s_j - \min_j s_j$$

If $R > \tau$, the dossier cannot be added to the agenda until an additional independent review has been attached. The threshold τ is stored as a configurable parameter rather than fixed in the model. This rule does not require reviewers to agree; it ensures that substantial disagreement remains visible to the council instead of being obscured by averaging.

States and Guarded Transitions

The procedure is represented as a state machine $\langle \Sigma, Ev, G, \delta \rangle$ with transition function $\delta: \Sigma \times Ev \times G \rightarrow \Sigma$. A transition occurs only when its guard evaluates to true for the current dossier. Table 1 lists the states, entry conditions, and admissible successors. Two structural properties are central. First, a state is not reachable from multiple predecessors without an explicit event, which allows the recorded history to be replayed. Second, each terminal state—approved, returned, or rejected—is reachable only after a signed protocol has been created, ensuring that every outcome is associated with a supporting decision record.

Table 1

States of the Council Procedure, Entry Guards, and Admissible Successors

State	Guard for entering the state	Admissible successor states
assembled	All mandatory documents are present; each file version is fixed by content hash.	dispersion_check
dispersion_check	At least m_{min} expertise records are attached.	agenda_listed; additional_review (if $R > \tau$)
additional_review	The dispersion guard failed; an additional expert is assigned.	dispersion_check
agenda_listed	The dispersion guard passed; the agenda is approved and circulated with a fixed reading window.	session_open
session_open	The chair opened the session; the presence list is recorded.	voting_open; postponed
voting_open	The quorum guard $q \geq q_{min}$ is satisfied; ballot tokens are issued.	voting_closed

State	Guard for entering the state	Admissible successor states
voting_closed	The ballot window elapsed or the chair closed voting; the tally is computed.	protocol_draft
protocol_draft	The quorum record, tally, and required rationale fields are complete.	protocol_signed
protocol_signed	The chair's electronic signature is verified.	ministry_review
ministry_review	The signed protocol and dossier-version hashes are transferred.	approved; returned; rejected
approved / returned / rejected	The ministry-level decision is recorded; a rationale is required for non-positive outcomes.	archived

Quorum, Ballots, and Tally

Let P denote the set of council members and $P_p \subseteq P$ the subset recorded as present. The quorum ratio and guard are

$$\mathbf{q = |P_p| / |P|\ ,\quad guard:\ q \geq q_{min}}$$

Each present member casts $b_i \in \{+1, 0, -1\}$, producing counts n_+, n_0, and n_-. Two approval ratios are possible:

$$\theta_1 = n_+ / |P_p| \qquad \theta_2 = n_+ / (n_+ + n_-)$$

The two rules differ in whether abstentions are included in the denominator, and this distinction can change the outcome. The applicable rule is specified by the council's regulation and stored when the session opens, together with q_{min} and the approval threshold θ_{min}. Binding the rule before ballots are known prevents retrospective selection of a counting rule.

Sealed Ballots With a Recomputable Tally

Individual vote confidentiality and tally verifiability can be supported simultaneously by separating identity from ballot content. When a session opens, the system issues each present member a single-use random token r_i. Two records are then stored separately:

$$\text{participation: } \langle\ sid, u_i, ballot_cast, t\rangle \qquad \text{ballot: } \langle\ sid, r_i, b_i, t\rangle$$

The participation record establishes that member u_i cast a ballot without revealing the selected option; the ballot record stores the choice but links it only to a token. For each ballot, the system also publishes a commitment $c_i = H(b_i \parallel r_i \parallel sid)$ to the session board. A member who retains r_i can verify inclusion of the ballot, while an auditor can recompute n_+, n_0, and n_- from the stored ballots and compare the result with the tally reported in the protocol.

This design has an important limitation. It protects ballot content from other members, applicants, and subsequent readers of the record, but not from an administrator who can simultaneously access both stores and the token-issuance log. Stronger protection would require organizational separation of duties or threshold cryptography. For councils of approximately 10 to 15 members, organizational separation is likely to be the more proportionate control.

Protocol Generation Over Complete Session States

The protocol is generated from recorded session data rather than drafted retrospectively. Over the domain of complete session states, it is defined as

$$\Pi = f(\sigma, Q, T, M, V_h)$$

where Q is the quorum record, including the presence list; T is the tally; M is the decision rationale, which is mandatory for negative and conditional outcomes; and V_h contains the version hashes of all documents reviewed by the council. Protocol generation is permitted only when each required argument is present. If any required element is missing, no draft protocol is produced. This constraint converts protocol completeness from a procedural expectation into a system-enforced condition.

Tamper-Evident Audit Chain

Each operation is stored as an audit entry linked to its predecessor:

$$a_k = \langle u_k, t_k, o_k, m_k, r_k, h_{k-1} \rangle \quad , \quad h_k = H(a_k)$$

where u denotes the actor, t the timestamp, o the operation, m the module, r the result, and h_{k-1} the hash of the preceding entry, with h_0 as a fixed genesis value. Verification recomputes the chain. Altering entry a_j invalidates each subsequent hash h_k for $k \geq j$, making local modification detectable. Because a sufficiently privileged actor could attempt to rewrite the entire chain, the current chain head h_k is periodically anchored to an external register, such as a notarized timestamp service or a separate institutional log. External anchoring limits the period in which a complete undetected rewrite could occur to the interval since the most recent anchor.

At the second tier, the existing chain continues rather than restarting, so the ministry-level decision inherits the evidentiary history of the STC stage. This shared chain also supports a concordance measure between the two levels. If A is the number of STC decisions confirmed without change by the ministry-level council and N is the total number of transferred decisions, concordance is C = A/N. Divergent decisions are not classified as errors; their rationales are indexed because recurring divergence may indicate criteria that the two levels interpret differently.

Table 2

Components of the Decision-Support Model and the Property Enforced by Each Component

Component	Formal object	Property enforced
Versioned dossier	$D = \langle id, A, E, V, \sigma, H \rangle$	A protocol reference resolves to one byte sequence, preventing version drift.
Dispersion guard	$R = \max_j s_j - \min_j s_j$, threshold τ	Substantial expert disagreement remains visible to the council rather than being obscured by averaging.
State machine	$\delta: \Sigma \times Ev \times G \rightarrow \Sigma$	Every outcome has a defined, replayable procedural path.
Quorum and rule parameters	$q \geq q_{min}$; θ_1 or θ_2; θ_{min}	The counting rule is fixed before ballots are known.
Sealed ballot	$\langle sid, r_i, b_i \rangle$ plus commitment c_i	Ballot confidentiality coexists with an independently recomputable tally.
Protocol generator	$\Pi = f(\sigma, Q, T, M, V_h)$, total	No decision record can be issued with a required evidence field missing.

Component	Formal object	Property enforced
Audit chain	$h_k = H(a_k)$ with external anchoring	Retroactive editing is detectable rather than merely prohibited.
Two-tier link	$C = A / N$	Ministry review inherits rather than restarts the evidentiary history.

Results

Figure 1 presents the sequential process generated by the model. Aggregated expertise results are followed by dossier preparation and validation, STC review, closed voting, protocol generation, ministry-level review, and one of three recorded outcomes: approval, return for revision, or rejection. The supporting functions shown in the figure—agenda management, access control, notifications, and the audit log—provide data or controls required by the guards defined in Table 1.

Figure 2 presents the same design as a module architecture rather than a sequence. Expertise results, the project dossier, and supporting documents enter as inputs. Review materials, agenda management, closed voting, protocol generation, the decision archive, notifications, and the audit log form the operational core. The resulting council decision, protocol, and transfer to the next administrative stage are outputs. The audit log is treated as an integrated module because each operation is recorded synchronously; a log reconstructed after the fact would not satisfy the chain property defined in the audit model.

Worked Example

Consider a council of 11 members, of whom eight are present, with $q_{min} = 2/3$ and $\theta_{min} = 2/3$. The quorum ratio is $q = 8/11 \approx 0.727$, so the quorum guard is satisfied. The ballots yield $n_+ = 5$, $n_- = 2$, and $n_0 = 1$. Under the present-member rule, $\theta_1 = 5/8 = 0.625 < 0.667$, and the motion fails. Under the valid-ballot rule, $\theta_2 = 5/7 \approx 0.714 \geq 0.667$, and the motion passes.

The example shows that a single abstention can determine the outcome in a small council. The counting rule must therefore be fixed before voting begins. In the proposed model, the rule is bound at session opening and printed in the protocol with the tally, allowing a later reviewer to reproduce the decision.

The dispersion guard has a similar effect at an earlier stage. Suppose three experts return weighted totals of 84, 81, and 58, yielding $S = 74.3$ and $R = 26$. If $\tau = 20$, the dossier cannot be placed on the agenda until a fourth independent review is obtained and the guard is reassessed. If only the aggregate score S were reported, the extent of disagreement among reviewers would not be visible to the council.

A completed cycle therefore produces a replayable decision record comprising the presence list, the applicable counting rule, the tally, document-version hashes, the decision rationale, and the ordered, anchored audit entries. The principal design objective is procedural replayability rather than processing speed.

Measurement Framework for the Council Stage

Aggregate measures of digitalization can obscure the contribution of individual modules. Performance estimates reported for the broader platform combine submission, expertise, council review, and monitoring and therefore cannot be attributed specifically to the council stage. For that reason, council-level evaluation requires measures derived from council-stage data.

Council-level evaluation therefore requires dedicated instrumentation. Table 3 defines eight metrics, their source fields, and their aggregation windows. Each metric can be derived from the audit chain and session records without additional manual reporting. The table specifies measurement procedures rather than empirical results; values must be calculated from deployment logs for a specific program cycle. Comparisons across cycles are interpretable only when q_{min}, θ_{min}, and τ remain unchanged or when differences in those parameters are explicitly accounted for.

Table 3

Metrics of the Council Stage: Definitions, Source Fields, and Measurement Windows

Metric	Definition	Source and window
Dossier completeness at agenda close	Share of agenda items whose mandatory attachments and version hashes were all present when the agenda was fixed	Dossier state log; per session
Reading window observed	Share of members who opened the materials before the session, and median lead time	Access log; per session
Quorum compliance	Share of sessions in which the recorded presence satisfied $q \geq q_{min}$	Presence records; per cycle
Tally verifiability	Share of sessions whose tally, recomputed from stored ballots, matches the figure printed in the protocol	Ballot store and protocol; per cycle
Protocol latency	Hours from the closing of voting to availability of the signed protocol	Audit chain timestamps; per session
Agenda-to-decision latency	Calendar days from agenda approval to the recorded ministry-level decision	Audit chain timestamps; per cycle
Two-level concordance	$C = A / N$, share of STC decisions confirmed unchanged at ministry level	Decision records of both tiers; per cycle
Chain integrity	Share of verification runs in which the recomputed chain matches all stored hashes and anchors	Scheduled verification job; monthly

Two metrics warrant particular attention. Reading-window observance indicates whether members accessed the materials before the session and helps distinguish procedural efficiency from substantive engagement. Two-level concordance is inexpensive to compute once both tiers share an evidentiary chain. A sustained decline in C across several cycles may indicate that the two levels are applying criteria differently, an issue that is difficult to identify when each tier maintains separate records.

Discussion

For the secretariat, the design reduces retrospective reconstruction because attendance, tallies, and document hashes are recorded before protocol generation. At the ministry level, the protocol arrives with its evidentiary chain, which can simplify confirmation and make divergent decisions easier to document. Applicants also receive a more consistent record because the rationale for negative or conditional outcomes is a required field.

Improved traceability should not be conflated with improved decision quality. Recording actors, timestamps, and procedural steps makes a decision more attributable and auditable, but it does not make the underlying judgment correct. Research on expert judgment provides no basis for assuming that electronic voting improves assessment quality (Bornmann, 2011; Cicchetti, 1991; Kahneman et al., 2021; Marsh et al., 2008). The dispersion guard instead preserves evidence of disagreement for the council to consider.

Formalization also creates a risk of procedural compliance without substantive review. A council could satisfy most metrics in Table 3 while giving limited attention to the dossier. Including reading-window observance partly addresses this risk by measuring whether members accessed the materials before the session. The framework should therefore be interpreted as a set of procedural indicators rather than a complete measure of review quality.

The design preserves the allocation of authority established by regulation. The system checks document completeness, routes dossiers, calculates aggregates, flags dispersion, and generates protocols, but it does not cast votes, reweight expert opinions, or recommend outcomes. The decision-support function is intentionally procedural rather than predictive.

Scientific Contribution and Novelty

The contribution lies in integrating established techniques—state machines, hash chains, and commitment mechanisms—into a single specification for two-tier council review. The resulting design addresses four requirements simultaneously: legal defensibility of the record, ballot confidentiality, tally verifiability, and continuity of evidence across administrative levels.

Four features distinguish the proposed specification. First, modeling the council decision as a guarded transition over a versioned dossier makes decision admissibility verifiable from the record itself. Second, separating the participation record from ballot content and adding a session-specific commitment supports ballot confidentiality alongside recomputable tallies. Third, defining protocol generation over complete session states makes completeness a system property rather than a clerical instruction. Fourth, the STC–ministry concordance metric becomes available once both levels write to a continuous evidentiary chain and can be used to identify recurring patterns of interlevel divergence.

Binding the counting rule as a session parameter is also methodologically significant. Social-choice research shows that plausible aggregation rules can produce different outcomes from the same underlying preferences (Arrow, 1951; Brams & Fishburn, 1978). Recording the rule in force before ballots are known is therefore necessary for reproducibility.

Practical Significance and Implementation Notes

The model can be implemented using the module structure shown in Figure 2 without changing the councils' legal allocation of authority because it governs the sequence and completeness of records rather than who makes the decision. Parameters that vary across councils, including q_{min}, θ_{min}, the abstention rule, τ, m_{min}, and the reading-window length, should be stored in a council-specific parameter set rather than hard-coded. Regulatory amendments can then be implemented as configuration changes and recorded in the audit chain.

Three implementation issues require particular attention. Electronic-signature integration determines whether the protocol_signed state represents a verifiable legal act and depends on the national certification infrastructure. Connectivity failures during sessions also require an offline procedure. One practical fallback is a signed paper attendance list and ballot record that are reconciled with the digital chain within a defined period, with the reconciliation itself logged. Finally, auditor separation must be enforced at the database-permission level; a read-only interface connected to an account with write privileges does not provide meaningful separation of duties.

Implementation should initially run in parallel with the existing paper procedure for one program cycle. Although parallel operation increases administrative effort, it provides an opportunity to identify discrepancies between written voting rules and established practice before the digital workflow becomes the sole procedural record.

Limitations

This study specifies a design and its formal properties but does not report a controlled comparison with the paper-based procedure. The metrics in Table 3 are proposed measures rather than observed results. Ballot confidentiality is maintained against members and later readers but not against an administrator who can access both storage systems simultaneously. In very small councils, confidentiality may also be weakened by inference across repeated votes; cryptographic controls cannot fully prevent such inference. All proposed metrics depend on the completeness and accuracy of the underlying logs, so missing attendance records, for example, could bias quorum-compliance estimates. The model also assumes that councils operate according to their formal rules. When written regulation and actual practice diverge, the system can document the discrepancy but cannot resolve it by itself.

Conclusion

Council review in state research programs can be represented as a controlled information process without reallocating decision authority. A versioned dossier, guarded procedural states, confidential but verifiable ballots, evidence-dependent protocol generation, and an externally anchored audit chain together produce a decision record that can be replayed rather than reconstructed. The proposed metrics, including concordance between STC and ministry-level decisions, provide a basis for evaluating council procedures across program cycles. The next empirical step is an instrumented pilot conducted across a complete program cycle and compared with the parallel paper procedure using the measures defined in Table 3.

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LIPID AND FATTY ACID COMPOSITION OF *METHYLOBACTERIUM DANKOOKENSE* 3HXI AND *METHYLOBACTERIUM FUJISAWAENSE* 1HXI BIOMASS

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ABSTRACT. *Methylotrophic bacteria are promising biotechnological objects because of their ability to convert one-carbon compounds into microbial biomass and other valuable cellular components. This study comparatively evaluated the total lipid content and fatty acid composition of Methylobacterium dankookense 3HXI and Methylobacterium fujisawaense 1HXI biomass. The strains were cultivated for 5 days at 35 °C and 200 rpm in liquid K medium supplemented with 1% methanol. Biomass was harvested by centrifugation at 10,000 rpm for 20 min at 4 °C, washed three times with distilled water and lyophilized. Total lipids were extracted with chloroform–methanol (2:1, v/v) according to the Folch method. Fatty acid methyl esters were analyzed by gas chromatography using an Agilent 6890N instrument equipped with a flame-ionization detector and an HP-5 capillary column. Total lipid contents were 5.36 and 5.12%, respectively. Unsaturated fatty acids predominated in both strains, accounting for 78.99 and 78.06% of the detected fatty acids. The C18:1 fraction was dominant, reaching 77.06% in M. dankookense 3HXI and 73.40% in M. fujisawaense 1HXI. The results extend the biochemical characterization of the studied methylotrophic bacteria and provide a basis for further evaluation of their biotechnological potential.*

Keywords: *Methylobacterium, M. dankookense, M. fujisawaense, methylotrophic bacteria, biomass, total lipids, fatty acids, C18:1, gas chromatography.*

INTRODUCTION

Growing global demand for protein has intensified the search for biotechnological raw materials that can complement conventional protein sources. Single-cell protein (SCP) derived from microbial biomass is considered a promising route for producing protein-rich food and feed ingredients [1, 2]. Bacterial SCP is attractive because microorganisms grow rapidly, can achieve high biomass productivity, and may utilize substrates that do not directly compete with agricultural crops [1].

Methylotrophic bacteria are of particular interest because they can use methanol and other one-carbon (C1) compounds as carbon and energy sources. Gundupalli et al. [1] emphasized that the capacity of *Methylobacterium* species to utilize C1 substrates, together with their biochemical biomass composition, makes them a promising group for bacterial SCP production.

The biotechnological versatility of methylotrophic biomass has also been demonstrated experimentally. Simões et al. [3] cultivated *Methylobacterium organophilum* on methanol and reported the formation of cellular biomass together with carotenoids, exopolysaccharides and

polyhydroxyalkanoates, supporting the view of methylotrophic biomass as a multicomponent biotechnological raw material.

Lipids are important structural and functional components of bacterial cells and contribute to membrane physicochemical properties and adaptation to environmental conditions. Therefore, determination of total lipid content and fatty acid profiles is useful for the biochemical characterization of biotechnologically relevant strains.

Cellular fatty acid profiles of *Methylobacterium* commonly contain a high proportion of C18:1 monoenoic fatty acids. In the original description of *M. dankookense* SW08-7T, C18:1 ω7c was reported as the major cellular fatty acid [4]. C18:1 ω7c has also been reported as a dominant or major component in *M. indicum* and other representatives of the genus [5, 6], and comparative taxonomic studies involving *M. fujisawaense* likewise indicate a predominance of C18:1 ω7c [7].

Bacterial fatty acid profiles may vary with species, strain, cultivation conditions, physiological state and analytical methodology. Consequently, direct experimental characterization of the lipid fraction is required for individual strains considered for biotechnological applications.

The aim of this study was to determine the total lipid content of *Methylobacterium dankookense* 3HXI and *Methylobacterium fujisawaense* 1HXI biomass, comparatively characterize their fatty acid profiles, and relate the results to published data for *Methylobacterium*.

MATERIALS AND METHODS

Bacterial strains and cultivation conditions

Methylobacterium dankookense 3HXI and *Methylobacterium fujisawaense* 1HXI, previously isolated and identified by molecular-genetic methods, were used in this study. Their nucleotide sequences were deposited in the NCBI GenBank database under accession numbers PX924540.1 and PX924362.1, respectively. The strains were cultivated in liquid K medium supplemented with 1% methanol. The medium contained (g/L): KH2PO4, 2.0; (NH4)2SO4, 2.0; MgSO4·7H2O, 0.025; NaCl, 0.5; FeSO4·7H2O, 0.002; distilled water to 1 L; methanol, 1%; initial pH 7.2. Cultivation was performed at 35 °C on a shaker at 200 rpm for 5 days. After cultivation, bacterial biomass was harvested by centrifugation at 10,000 rpm for 20 min at 4 °C, washed three times with distilled water and lyophilized.

Extraction of total lipids

Total lipids (neutral lipids, glycolipids and phospholipids) were extracted according to Folch et al. [8]. Biomass samples were extracted three times with chloroform–methanol (2:1, v/v). Extraction was carried out with magnetic stirring at 50 °C for 1 h followed by standing without agitation. The extracts were separated by paper filtration and combined. The pooled extract was washed with 0.05% aqueous CaCl2 to remove non-lipid components. The chloroform phase was separated from the aqueous-methanol phase in a separatory funnel. Chloroform was removed on a rotary evaporator and residual solvent was removed by drying at a temperature not exceeding 50 °C to constant weight. Total lipid yield was expressed as a percentage of biomass mass.

Isolation of fatty acids and preparation of methyl esters

Fatty acids were isolated from total lipids using the recommended procedure [9]. Lipids were hydrolyzed with 10% KOH in methanol at a lipid-to-solution ratio of 1:10 by heating in a boiling water bath for 1 h. The resulting soaps were decomposed with 50% aqueous sulfuric acid. Free fatty acids were extracted three times with diethyl ether. The combined ether extracts were washed with distilled water to neutrality, dried over anhydrous sodium sulfate, and evaporated on a rotary evaporator. For gas chromatographic analysis, fatty acids were methylated with

diazomethane. The resulting fatty acid methyl esters (FAME) were purified by preparative thin-layer chromatography on silica gel using hexane:ether (8:2) as the solvent system.

Gas chromatographic analysis

FAME were analyzed using an Agilent 6890N gas chromatograph equipped with a flame-ionization detector and a 30 m capillary column coated with the non-polar HP-5 stationary phase. The analysis was performed over a temperature range of 150–250 °C. Helium was used as the carrier gas (30 mL/min). Fatty acid composition was expressed as the relative percentage of the detected fatty acid fraction.

RESULTS AND DISCUSSION

Total lipid content

The total lipid contents of the two methylotrophic bacterial biomasses were similar. *M. dankookense* 3HXI contained 5.36% total lipids, whereas *M. fujisawaense* 1HXI contained 5.12% (Table 1).

Table 1. Total lipid content of Methylobacterium biomass.

Strain	Total lipids, % of biomass mass
M. dankookense 3HXI	5.36
M. fujisawaense 1HXI	5.12

The close values indicate a comparable overall lipid fraction in the biomass of the two strains. However, total lipid content alone does not describe compositional characteristics; therefore, the fatty acid profiles were analyzed separately.

Fatty acid composition

Gas chromatographic analysis revealed profiles comprising saturated and unsaturated fatty acids in the total lipids of both strains (Table 2).

Table 2. Fatty acid composition of total lipids from M. dankookense 3HXI and M. fujisawaense 1HXI biomass.

Fatty acid	***M. dankookense* 3HXI, %**	***M. fujisawaense* 1HXI, %**
C10:0	0.13	–
C12:0	0.10	0.21
C14:0	0.27	0.49
C15:0	0.09	0.39
C16:0	9.65	15.04
C16:1	1.56	3.44
C17:0	0.57	0.59
C18:0	10.16	5.10
C18:1	77.06	73.40
C18:2	0.10	0.46
C20:0	0.02	0.12
C20:1	0.24	0.76
C22:0	0.02	–
C22:1	0.03	–
Σ saturated fatty acids	21.01	21.94
Σ unsaturated fatty acids	78.99	78.06

Unsaturated fatty acids predominated over saturated fatty acids in both strains. Their total proportions were 78.99% in *M. dankookense* 3HXI and 78.06% in *M. fujisawaense* 1HXI. The calculated unsaturated-to-saturated fatty acid ratios were 3.76 and 3.56, respectively.

The dominant component of the fatty acid profile in both strains was the C18:1 fraction, accounting for 77.06% in *M. dankookense* 3HXI and 73.40% in *M. fujisawaense* 1HXI. These

findings are broadly consistent with published chemotaxonomic characteristics of *Methylobacterium*. Lee et al. [4] reported C18:1 ω7c as the major cellular fatty acid in the *M. dankookense* SW08-7T type strain. High proportions of C18:1-type fatty acids have also been reported for *M. indicum* [5], *M. ajmalii* [6] and *Methylobacterium* taxa compared with *M. fujisawaense* [7].

The strains differed in several other major components. C16:0 was higher in *M. fujisawaense* 1HXI (15.04%) than in *M. dankookense* 3HXI (9.65%). In contrast, C18:0 was higher in *M. dankookense* 3HXI (10.16%) than in *M. fujisawaense* 1HXI (5.10%). C16:1 was also higher in *M. fujisawaense* 1HXI (3.44%) than in *M. dankookense* 3HXI (1.56%). Minor components C10:0, C22:0 and C22:1 were detected only in *M. dankookense* 3HXI at 0.02–0.13%; their physiological or taxonomic significance should not be overinterpreted without additional targeted experiments.

Methodological consideration in interpretation of the C18:1 fraction

Methodological differences should be considered when comparing the present results with taxonomic FAME data. In taxonomic studies, C18:1 fatty acids are often identified more specifically according to double-bond position, for example as C18:1 ω7c [4–7]. In the present study, FAME prepared from total lipids were analyzed by GC-FID using a non-polar HP-5 capillary column. Therefore, the dominant components detected at 77.06 and 73.40% are conservatively reported as C18:1 and are not assigned to C18:1 ω7c or C18:1 ω9c without additional isomer-specific confirmation.

Biotechnological significance

The current biotechnological interest in methylotrophic bacterial biomass is associated with its capacity to convert C1 substrates into cell mass. Recent reviews discuss *Methylobacterium*-based bacterial SCP as a promising platform for food and feed protein production [1, 2].

Studies with *M. organophilum* have demonstrated the production of biomass and additional metabolites using methanol as a carbon source [3]. Moreover, microbial biomass based on *Methylobacterium extorquens* has been experimentally evaluated as an alternative protein source in aquafeeds [10].

In this context, the presence of approximately 5% total lipids and a fatty acid fraction containing 78–79% unsaturated fatty acids expands the biochemical characterization of *M. dankookense* 3HXI and *M. fujisawaense* 1HXI. However, these lipid data do not directly demonstrate biological efficacy as feed. Digestibility, nucleic acid content, microbiological and toxicological safety, processing stability and in vivo feeding performance should be evaluated separately before practical feed application is proposed [1, 2, 10].

CONCLUSION

Comparative characterization of *Methylobacterium dankookense* 3HXI and *Methylobacterium fujisawaense* 1HXI biomass showed total lipid contents of 5.36 and 5.12%, respectively. Unsaturated fatty acids predominated in both strains, accounting for 78.99 and 78.06% of the detected fatty acid fraction. C18:1 was the dominant component, representing 77.06% in *M. dankookense* 3HXI and 73.40% in *M. fujisawaense* 1HXI. The strains also showed compositional differences in C16:0, C16:1 and C18:0. These results expand the biochemical characterization of the lipid fraction of the studied methylotrophic bacteria and support further comprehensive evaluation of their biotechnological potential.

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RATIONAL COMPOSITION OF COMBINE–TRUCK GROUPS FOR GRAIN HARVESTING UNDER UZBEKISTAN CONDITIONS: A CLOSED QUEUEING MODEL WITH FIELD VALIDATION

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Abstract. *Timely grain harvesting depends on how well combine harvesters and grain trucks are matched. In Uzbekistan, wheat area in Tashkent region stayed almost constant in 2023–2025 (about 102.5 thousand ha) while the combine fleet fell from 264 to 217 units, so each machine had to cover about 21% more area. This study proposes a method for choosing the number and loading level of trucks serving a harvesting group. The group is described as a closed queueing system, and a combine's grain throughput is derived from the threshing-unit capacity. Three combine models (CLAAS Dominator-130, New Holland TC 5.90, CASE 2366) were analysed for a three-combine group at a 31 km haul distance and a yield of 8.5 t/ha. Chronometric field observations differed from the model by 0.5–5.3%. Deterministic calculation overstated the combines' loading: with randomness included, combine utilisation did not exceed 0.80–0.84 at the deterministic truck count, and one to two extra trucks were needed. Raising CLAAS group utilisation from 0.71 to 0.93 shortened harvest duration by 23.3%. The model estimates a grain-loss reduction of 8.71 t per 100 ha, equal to 1,368 t (UZS 4.27 billion) for the 15,700 ha of Bekobod district. Sensitivity analysis showed that truck speed, haul distance and the number of combines in the group matter most. The method supports fleet planning for agro-clusters and farms.*

Keywords: grain harvesting; combine harvester; truck fleet; queueing theory; harvest logistics; Uzbekistan

1. Introduction

Food security rests on producing grain and also on bringing the crop in within a short agrotechnical window with minimal loss. Wheat remains the main food crop worldwide, and the largest producers (China, India and Russia) harvest more than 90 million tonnes each [1]. For all of them, the harvest is a coordinated chain: cutting, threshing, temporary storage in the combine bunker, unloading into a truck, hauling and reception. A mismatch at any link spreads along the whole chain. Too few trucks make combines wait with full bunkers; too many leave expensive trucks idle in the field.

Field logistics has been studied extensively. Routing and fleet-management models for in-field operations were developed by Bochtis and Sørensen [4–6] and reviewed in [7]. Later work applied infield logistics planning [8], discrete-event simulation of farm-scale grain transport [9], route optimisation for grain harvest [10], and collaborative scheduling of harvesters and transport units using heuristic and evolutionary algorithms [11, 12]. Transport optimisation during a harvesting campaign has also been shown for sugar beet [13]. Classical references on combine theory and machinery management give the basic capacity relationships [14, 15], and queueing theory provides the mathematical basis for service systems [17, 18]. In the Russian-language

literature, the matching of harvesting and transport machines has been treated in several doctoral and candidate theses [19–21].

Despite this body of work, most models either optimise routes for a given fleet or use deterministic capacity balances. Fewer studies determine the *number* of trucks for small groups of combines while accounting for random cycle times and for the technical condition of an ageing fleet. This is the situation in Uzbekistan, where fields are of moderate size, haul distances are long, and combines break down during the short harvest period.

The aim of this paper is to justify the rational number of trucks and the loading level of combines in a harvesting–hauling group, and to estimate the effect on harvest duration, grain loss and cost. The paper makes four contributions: (i) a throughput-based expression for combine grain capacity valid for high-yield fields; (ii) a method to determine the truck number from the continuity condition of the technological flow; (iii) a closed queueing model of the group with a utilisation criterion; and (iv) a multi-channel queueing model for mobile repair workshops serving the combines in season.

2. Relevance for Uzbekistan

Uzbekistan's population grew from just over 20 million in 1991 to more than 38.2 million on 1 January 2026 [2], so the demand for bread grain keeps rising while land and water are limited. The state supports the supply of agricultural machinery and its domestic production [3], and the national research programme for 2022–2026 includes calculation models for the rational structure of machinery fleets for grain, cotton, fruit-vegetable and rice clusters.

Table 1 shows the situation in Tashkent region. The sown area was stable, yet the number of combines fell by 17.8% in two years. Area per combine rose from about 390 to about 472 ha, and average yield was 8.8–9.3 t/ha. At these yields a combine's area productivity falls, because its speed is limited by the capacity of the threshing unit, so the same area takes longer to harvest. Bekobod district illustrates the problem: it has 15,700 ha of wheat with a yield of about 9.3 t/ha, and its crop ripens earlier than in several other districts, which shortens the harvest window.

Table 1. Wheat harvest indicators and combine fleet, Tashkent region, 2023–2025

Year	Area, ha	Gross yield, t	Mean yield, t/ha	Combines, units	Area per combine, ha*
2023	102,832	935,771	9.10	264	389.5
2024	102,753	950,228	9.25	254	404.5
2025	102,500	899,950	8.78	217	472.3

*Calculated by the authors as area divided by the number of combines.

Figure 1 presents the same trend: the area is flat while the fleet shrinks and the burden on each machine grows.

3. Current Problem and Research Gap

Three practical problems follow from the data above.

1. **Imbalance between combines and trucks.** Combine capacity and truck capacity are often chosen separately. When trucks are insufficient, the combine stops with a full bunker; when they are excessive, trucks queue.
2. **Deterministic planning.** Calculations that use average cycle times ignore the random nature of arrivals and service, which in a closed system lowers real combine loading.
3. **Ageing fleet and breakdowns.** Reported data show that in fleets with an average age above 16 years, harvest duration exceeded the norm by 2.0–2.5 times and crop loss

reached 16–20% [21]. Belt and chain drives, hydraulics and electro-hydraulic controls are the most failure-prone units [22, 23].

The gap is therefore a decision method that links combine capacity, bunker volume, truck body volume, haul distance and random service, and that can be used at farm level.

4. Proposed Solution and Methods

4.1 Combine grain capacity

When the forward speed is limited by the throughput of the threshing unit, grain capacity per hour is

$$W = 3.6 \cdot Q_{max} \cdot \tau / (1 + \delta_s)$$

where Q_{max} is the throughput of the combine (kg/s), τ is the shift-time utilisation coefficient (0.8) and δ_s is the straw-to-grain ratio (0.9). Substituting the speed from the throughput balance shows that the cutting width and the yield cancel out. Grain capacity is then independent of yield, while capacity per hectare falls as yield rises. If the yield is low and the calculated speed exceeds the agrotechnical maximum, the area-based formula applies instead. The condition was verified before use: for the 70–90 centner/ha range studied here the throughput-limited regime holds.

The bunker filling time is $T_b = 60 \cdot V_b \cdot k_b \cdot \rho_g / W$, with V_b the bunker volume (m^3), $k_b = 0.9$ the fill coefficient and $\rho_g = 0.78$ t/m^3 the grain bulk density. This time sets how often a truck must approach the combine.

4.2 Truck number from the continuity condition

Because the grain bulk density is low, the number of bunker loads that fit into a truck body is limited by body volume, not by payload. Load-capacity utilisation therefore ranged from 0.28 to 0.73. The truck number that keeps the technological flow uninterrupted is found from the ratio of truck cycle time (loading, haul in both directions, unloading, manoeuvring) to the interval between bunker fillings.

4.3 Closed queueing model

The group of n_k combines and c trucks is modelled as a closed queueing system. Combines generate unloading requests and trucks serve them. Cycle times are treated as random variables, and the model returns the combine-group utilisation η_k, the truck utilisation η_a and the mean truck waiting time for loading. The rational truck number c_r is the smallest c that satisfies the criterion $[\eta_k] = 0.9$. Base values were l = 31 km, mean truck speed 25 km/h, towing and unloading time 22 min, manoeuvring time 1.5 min and $n_k = 3$.

4.4 Mobile workshops

Breakdowns of N combines were described as a flow with parameter ω (1/h). A multi-channel queueing model gives the waiting time of a combine for repair and the share of downtime K_b as a function of the number of mobile workshops, with a repair time of 2 h.

4.5 Field observations and economic assessment

Chronometric observations of CLAAS Dominator-130 and CASE 2366 combines were made in Bekobod district. Model and field values were compared by relative difference $\Delta = |x_{exp} - x_{model}| / x_{exp} \cdot 100\%$. For the economics, the saved grain was valued at the April 2026 exchange price of UZS 3,123.9 thousand per tonne [24, 25], and the break-even cost of one additional truck-day was calculated as $C^* = \Delta G \cdot C_d / (M_{a,r} - M_{a,0})$, where ΔG is the grain saved and M_a the truck-days. Combine-day savings were not counted, so the estimate is conservative.

5. Results and Analytical Discussion

5.1 Combine performance

Table 2 lists the input parameters and the calculated performance at a yield of 7.0 t/ha.

Table 2. Combine parameters and calculated performance (yield 7.0 t/ha)

Indicator	CLAAS Dominator-130	New Holland TC 5.90	CASE 2366
Effective cutting width, m	3.80	4.94	5.22
Throughput Q_max, kg/s	3	5	7
Bunker volume, m³	3.2	5.2	6.0
Working speed, km/h	2.14	2.74	3.63
Area capacity, ha/h	0.65	1.08	1.52
Grain capacity, t/h	4.55	7.58	10.61
Bunker filling time, min	29.6	28.9	23.8
Daily capacity (10 h), ha/day	6.5	10.8	15.2

CASE 2366 is 2.3 times more productive in grain than CLAAS Dominator-130. At 8.5 t/ha the daily capacity falls to 5.3, 8.9 and 12.5 ha/day, respectively. Bunker filling times of 24–30 min define the rhythm of truck arrival.

A sensitivity check on the straw-to-grain ratio showed that reducing δ_s from 0.9 to 0.7 (for example, by a higher stubble height) raises CLAAS grain capacity by 11.8% (to 5.08 t/h), while raising it to 1.1 lowers capacity by 9.5%. The coefficient should therefore be measured, not assumed.

5.2 Agreement with field data

Table 3. Model results versus chronometric observations (yield 8.5 t/ha)

Indicator	Combine	Model	Field	Δ, %
Grain capacity, t/h	CLAAS Dominator-130	4.55	4.80	5.3
Bunker filling time, min	CLAAS Dominator-130	29.6	29.8	0.5
Grain capacity, t/h	CASE 2366	10.61	11.00	3.5
Bunker filling time, min	CASE 2366	23.8	24.5	2.8

Differences stayed between 0.5% and 5.3%. Field unloading took 4.0 min (CLAAS) and 3.6 min (CASE), and towing plus unloading of trucks took 18–22 min. The field data also support the model's key conclusion that grain capacity does not depend on yield.

5.3 Utilisation and truck number

Table 4 shows how utilisation changes with the number of trucks for a three-combine group at 31 km (Figure 2).

Table 4. Utilisation of the combine group (η_k) and trucks (η_a) versus truck number (n_k = 3, yield 8.5 t/ha, l = 31 km)

Trucks, c	CLAAS η_k	CLAAS η_a	New Holland η_k	New Holland η_a	CASE η_k	CASE η_a
3	0.710	0.842	0.556	0.913	0.395	0.960
4	0.843	0.751	0.696	0.858	0.513	0.934
5	0.926	0.659	0.807	0.796	0.620	0.904
6	0.969	0.575	0.888	0.729	0.715	0.869
7	0.989	0.503	0.941	0.662	0.797	0.829
8	0.996	0.444	0.972	0.599	0.862	0.785

Trucks, c	CLAAS η_k	CLAAS η_a	New Holland η_k	New Holland η_a	CASE η_k	CASE η_a
9	0.999	0.395	0.988	0.541	0.912	0.738

With the deterministic truck count, combine utilisation was only 0.843 (CLAAS), 0.807 (New Holland) and 0.797 (CASE). Under the criterion [η_k] = 0.9 the rational number of trucks is 5, 7 and 9, giving η_k of 0.926, 0.941 and 0.912. Beyond η_k ≈ 0.9 each additional truck adds little, while truck utilisation drops sharply: for the CLAAS group, the ninth truck is used only 39.5% of the time. Accounting for randomness added one to two trucks to the deterministic result.

5.4 Effect of haul distance and recommended composition

When the haul distance grows from 5 to 40 km, the rational number of trucks for a three-combine group rises from 3 to 6 (CLAAS) and from 4 to 11 (CASE) (Figure 3). Table 5 gives the recommended group composition.

Table 5. Recommended composition of a harvesting–hauling group (combines + trucks)

Haul distance, km	CLAAS Dominator-130	New Holland TC 5.90	CASE 2366
10	3 + 3 HOWO	3 + 4 SHACMAN	3 + 5 HOWO
20	3 + 4 HOWO	3 + 5 SHACMAN	3 + 7 HOWO
31	3 + 5 HOWO	3 + 7 SHACMAN	3 + 9 HOWO

For plots of 400–800 m length, the best plot width is 68–105 m, and working three to four combines on one plot is appropriate.

5.5 Technical–economic effect

Table 6. Effect of the rational group composition per 100 ha (yield 8.5 t/ha, l = 31 km)

Indicator	CLAAS base	CLAAS proposed	New Holland base	New Holland proposed	CASE base	CASE proposed
Trucks	3	5	3	7	3	9
Combine utilisation η_k	0.710	0.926	0.556	0.941	0.395	0.912
Truck utilisation η_a	0.842	0.659	0.913	0.662	0.960	0.738
Harvest duration, days	8.78	6.73	6.73	3.97	6.76	2.93
Combine-days	26.3	20.2	20.2	11.9	20.3	8.8
Truck-days	26.3	33.7	20.2	27.8	20.3	26.3
Grain-loss reduction, t	–	8.71	–	11.70	–	16.27

For the CLAAS group, adding two trucks shortens harvest duration by 23.3% (8.78 to 6.73 days), saves 6.1 combine-days and costs 7.3 extra truck-days. The estimated grain saving is 8.71 t per 100 ha, worth UZS 27.21 million. For all 15,700 ha of Bekobod district the saving is 1,368 t, or UZS 4.27 billion. The proposed composition pays off if one truck-day costs less than UZS 3.72 million (CLAAS), 4.78 million (New Holland) or 8.37 million (CASE). Because the more productive combines load each truck more heavily, the benefit grows with combine capacity.

5.6 Sensitivity analysis

With one parameter changed at a time, truck speed had a strong effect: when speed fell from 40 to 20 km/h, the rational truck number rose from 4 to 6 (CLAAS), 5 to 8 (New Holland) and 7 to 11 (CASE) (Figure 4). Haul distance and the number of combines in the group were also influential. In contrast, a four-fold change in towing and unloading time (10 to 40 min) changed the truck number by no more than one unit. Raising the target utilisation [η_k] from 0.80 to 0.98 increased the CLAAS truck number from 4 to 7, showing that beyond 0.9 the added cost is high.

5.7 Mobile repair workshops

Field and literature data show that in the aged fleet the failure flow parameter was 0.066–0.086 1/h, and failures needing a mobile workshop occurred at 0.03–0.04 1/h. Table 7 illustrates the model for N = 20 combines.

Table 7. Share of combine downtime K_b versus number of mobile workshops (N = 20, repair time 2 h)

Failure flow ω, 1/h	1 workshop	2 workshops	3 workshops	4 workshops	Rational number
0.02	0.100	0.044	0.039	0.039	2
0.04	0.383	0.116	0.081	0.075	3
0.06	0.583	0.242	0.136	0.114	4

For Bekobod conditions (ω = 0.03–0.04 1/h) three workshops per 20 combines are justified. A single workshop leaves almost 40% of combine time lost at ω = 0.04.

6. Discussion

The results confirm two points that are often overlooked in practice. First, with random cycle times, a truck count taken from a deterministic balance leaves the combines underloaded, in line with the general behaviour of closed service systems [17, 18]. Second, there is a utilisation level (about 0.9) above which extra trucks produce little gain; this offers farm managers a clear stopping rule instead of the common "add trucks until the combines stop waiting" approach.

The approach complements route-oriented and simulation studies [4–12], which optimise movements of a given fleet, by answering a prior question: how many machines to assign. It requires only a few measurable inputs (capacity, bunker and body volume, distance, speed, unloading time), which makes it usable in farms that cannot run discrete-event simulation. The result that combine grain capacity is independent of yield in the throughput-limited regime also explains why high-yield fields slow down the harvest even with unchanged machines.

Limitations. Field validation covered combine capacity and bunker filling time for two combine models in one district; the fleet-level effects (harvest duration, grain loss and cost) are model-based estimates. The loss reduction depends on the loss–time relationship assumed, and the economic estimate takes the exchange price of a single month. Road conditions and queues at reception points were represented only through average speed and unloading time. Future work should validate fleet-level results over several seasons, include storage reception delays, and compare the method with simulation-based planning.

7. Conclusions

1. In Tashkent region in 2023–2025, wheat area stayed near 102.5 thousand ha while the number of combines decreased from 264 to 217 (17.8%), which raised the area per combine by about 21% and makes the rational composition of harvesting groups a practical necessity.
2. In the throughput-limited regime, combine grain capacity is $W = 3.6 \cdot Q_{max} \cdot \tau/(1+\delta_s)$ and does not depend on yield. Calculated capacities of 4.55, 7.58 and 10.61 t/h differed from field data by 0.5–5.3%.
3. The group modelled as a closed queueing system gives combine utilisation of 0.80–0.84 at the deterministic truck count. Using $[\eta_k] = 0.9$, a three-combine group at 31 km needs 5 trucks (CLAAS Dominator-130), 7 (New Holland TC 5.90) and 9 (CASE 2366).

4. For the CLAAS group, the rational composition raises combine utilisation from 0.71 to 0.93, shortens harvest by 23.3% and reduces estimated grain loss by 8.71 t per 100 ha, which is 1,368 t (UZS 4.27 billion) for Bekobod district.
5. Truck speed, haul distance and the number of combines are the most influential parameters. Three mobile workshops per 20 combines are advisable at failure flows of 0.03–0.04 1/h.

Author Contributions, Funding and Declarations

Conceptualisation, methodology and field observations: N.B.R.; supervision: K.A.S. [complete according to the target journal's CRediT form]. Funding: [state]. The authors declare no conflict of interest. The work builds on the first author's doctoral dissertation (Agricultural Mechanization Research Institute, 2026); related earlier publications by the authors must be cited and the overlap disclosed in the cover letter [add citations].

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THE IMPORTANCE OF DIGITALIZATION IN ECONOMIC DEVELOPMENT OF THE GOVERNMENT

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https://doi.org/10.5281/zenodo.19492171

Abstract. *Uzbekistan is focused on studying how digitalization influences economic growth as well as various sectors of the national economy. The research primarily relies on a review of international literature and an examination of key financial indicators related to the digital economy within a specific country. During the study, statistical data were collected, illustrated and analyzed using charts and tables. Additionally, a regression analysis has been conducted to evaluate the relationship between the development of the ICT and logistics sectors and real GDP. The article also presents key findings along with practical recommendations regarding the process of digitalization.*

Keywords: *real GDP, digital economy, e-service, e-commerce, ICT.*

Introduction

In parallel with global economic advancement, the pace of information technology development and data exchange has significantly accelerated. The concept of the digital economy refers to the extensive network of continuous online interactions among organizations, individuals, data systems, technologies, and processes that underpin economic activities. It is fundamentally based on the integration and interaction of organizations, individuals, and machines through the Internet, digital platforms, websites, mobile applications, and related technologies (Nguyen, 2023). Contemporary research highlights that economic agents increasingly operate in an environment where transactions are facilitated through smartphones, social networks, and online marketplaces. Empirical evidence suggests that, particularly in developed economies, improved accessibility to information contributes to enhanced productivity and greater operational efficiency (Guariso & Nyqvist, 2018).

In the contemporary digital era, the Internet has evolved into a critical element of corporate governance, transitioning from its initial role as a relatively low-cost communication medium to a strategic infrastructure. Technological advancement plays a pivotal role in enhancing economic performance and improving societal welfare across countries (Korotkevich, 2019). The adoption of emerging technologies may generate short-term labor displacement; however, it simultaneously creates new employment opportunities in the medium to long term (Sellar, 2019). In the context of rapid technological advancement, national economies can achieve stable and sustained growth through the effective integration of practical and innovative technologies. In pursuit of sustainable development, developed countries are increasingly prioritizing advanced solutions such as 3D printing and biofuel engineering (Shor et al., 2022).

Technological innovations—including the digitalization of public transportation systems, the expansion of online banking services, the development of internet-based marketing, the

implementation of e-learning platforms, and the enhancement of intercity communication infrastructures—have been successfully adopted in many developing economies (Kotevski & Milenkoski, 2018). Among the key constraints to economic growth are inefficiencies in time management and relatively low productivity levels. Addressing these challenges requires the widespread implementation of automation, digitalization, and innovative technologies to enhance efficiency across sectors and industries (Yano, 2016).

At advanced stages of economic development, employment tends to shift toward digital and remote service sectors, surpassing traditional industries such as manufacturing and agriculture. Moreover, economic activity is no longer confined to specific geographic locations; instead, it operates within a globalized framework that enables individuals to engage in work across borders. Consequently, governments are increasingly focusing on strengthening the ICT labor force (Clemons, 2007). Ensuring an effective and well-managed transition to the digital economy remains a critical responsibility of policymakers. Given that the potential benefits outweigh the associated risks, it is essential to implement policies aimed at reducing structural barriers, fostering job creation, and supporting sustainable economic growth (Chatani, 2012).

Literature review

The digital economy is fundamentally grounded in the extensive adoption of information and communication technologies (ICT) across all sectors to enhance productivity and efficiency. It represents an economic system in which digital and computer-based technologies play a dominant role. Within this framework, networking and communication infrastructures serve as a global platform that enables individuals and organizations to plan, interact, exchange information, and collaborate regardless of geographical boundaries (Alam et al., 2022). A comprehensive understanding of the Fourth Industrial Revolution (4IR), including its emerging technologies and associated risks, is essential for all countries. The rapid advancement of innovative technologies has generated diverse perspectives regarding the implications of automation, global supply chains, and outsourcing on employment patterns. As noted by Krichen (2022), the digital revolution is expected to continue evolving through technological progress, with an increasing emphasis on data-driven systems and artificial intelligence.

In the context of sectoral transformation, full digitalization of banking systems is considered crucial for ensuring transparency and operational efficiency (Naheem, 2015). Similarly, promoting digital information exchange in agriculture remains a key priority during the ongoing phases of industrial transformation (Oguamanam, 2018).

However, the expansion of artificial intelligence also raises significant ethical concerns, including the protection of human rights and societal values. Balancing innovation with ethical regulation, while simultaneously enhancing individual and societal well-being, remains a complex but essential challenge.

Furthermore, managing the integration of human resources and technological advancements within the digital economy presents considerable difficulties, particularly in developing countries, where aligning these elements with inclusive and equitable growth objectives is critical (Joseph & Marrow, 2017).

At the same time, emerging research highlights substantial opportunities related to new organizational structures driven by artificial intelligence, human capability enhancement, and national digital economies (Zhang et al., 2021). The integration of science, technology, and big data into industrial processes can significantly improve access to information, reduce transaction costs, and enhance overall competitiveness (Sahay et al., 2020).

Ensuring an effective transition to the digital economy requires that its advantages outweigh potential drawbacks, particularly in terms of employment challenges, which should be mitigated through sustained economic growth and development (Elsafty & Elzeftawy, 2022). In this regard, many developing countries have implemented ICT strategies, legal frameworks, and policy measures aimed at fostering transparency, accountability, and socio-economic progress (Aziz & Naima, 2021).

Methodology

This study investigates the role of the digital economy in promoting economic development. It employs a comparative analytical approach to examine the impact of digitalization across various economic sectors.

Research Results

In line with the "Digital Uzbekistan – 2030" strategy, comprehensive measures are being implemented to promote digital transformation across economic sectors and regions. These include the development of state information systems, expansion of electronic public services, and digital reforms in key areas such as education, public administration, the judiciary, and the financial and banking sectors.

The introduction of a unified rating and evaluation framework to assess the level of digital economy and e-government development across economic sectors, social domains, and regions has enabled the establishment of an effective interagency coordination mechanism. This framework supports the systematic evaluation and implementation of sectoral and regional digital development programs.

According to the GovTech Enablers Index published by the World Bank, Uzbekistan achieved 9th place globally in 2025, particularly excelling in digital skills and innovation in public service delivery. This ranking underscores the significant role of the digital economy in advancing government digitalization policies and fostering economic growth.

Furthermore, the expansion of digitalization is increasingly recognized as a key determinant of a country's investment attractiveness. Compared to 2020, Uzbekistan improved its position by 71 places, with its index score rising substantially from 0.617 to 0.958. Consequently, the country reinforced its standing within the "High GovTech Maturity" category (Category A).

The index evaluates digital transformation in public administration across four principal dimensions: core government systems, the provision of online public services, digital citizen engagement, and enabling factors that support GovTech development.

By the end of 2025, Uzbekistan ranked first in Central Asia and entered the global top ten, alongside leading countries such as South Korea, Australia, India, and Canada. Furthermore, these results demonstrate that sustained investment in digital infrastructure and human capital is essential for maintaining progress in GovTech development.

Strengthening institutional capacity and expanding access to digital services can further enhance public sector efficiency and inclusiveness. In addition, continued policy support for innovation and digital transformation will contribute to long-term economic resilience. Overall, Uzbekistan's achievements highlight its potential to become a regional leader in digital governance and technology-driven development.

This is clearly demonstrated in the next figure.

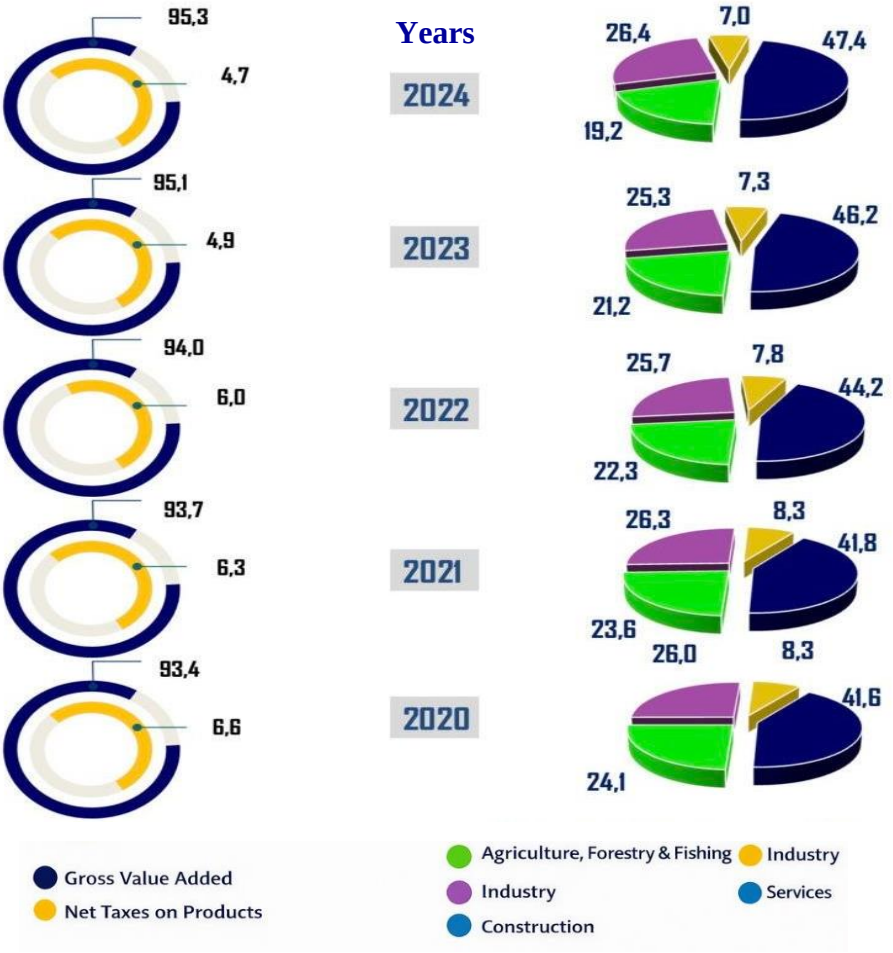


Figure 1. GDP composition by types of economic activity, in % of total

In Figure 1, we see the analysis of the growth dynamics In 2024, the Gross Domestic Product (GDP) of Uzbekistan reached 1.45 quadrillion soums, representing an annual growth rate of 6.5%. Based on the average exchange rate, this corresponds to approximately 115 billion US dollars. In addition, GDP per capita rose to 39.1 million soums, equivalent to about $3,093. These statistics were officially reported by the Agency of Statistics of Uzbekistan. The structural composition of the national economy has undergone notable changes in recent years. The share of the services sector increased from 46.2% to 47.4%, indicating a gradual shift toward a service-oriented economy. Similarly, the industrial sector expanded its contribution from 25.3% to 26.4%, reflecting ongoing industrial development. In contrast, the share of agriculture declined from 21.2% to 19.2%, suggesting a relative reduction in its role within the overall economic structure. The construction sector also experienced a slight decrease, with its contribution falling from 7.3% to 7%.

With regard to sectoral dynamics, the contribution of information and communication technology (ICT) services reached 2.4% of GDP, while the broader information and telecommunications sector accounted for 2.7%. At the same time, transportation and logistics services represented 5.4% of total GDP, highlighting their growing importance in supporting economic activity. The role of small businesses and private entrepreneurship has also strengthened significantly. Their share in GDP increased from 51.2% to 54.3%, demonstrating the positive outcomes of economic reforms aimed at promoting private sector development and enhancing entrepreneurial activity in Uzbekistan. According to preliminary estimates, which incorporate the results of statistical assessments of the informal and shadow economy, the total volume of market

services in Uzbekistan for the period January–December 2025 reached 1,050.3 trillion soums, representing a 14.7% increase compared to 2024. In the previous year, the volume of services amounted to 840.1 trillion soums, reflecting a growth rate of 13.3% relative to 2023.

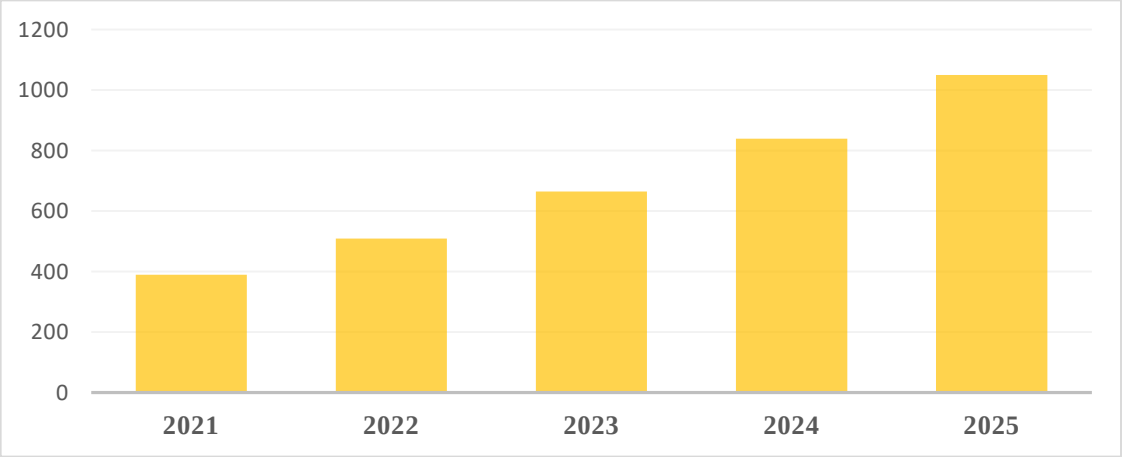


Figure 2. The volume market services provided, *in trillion sums*

In Figure 2, illustrates the volume of market services provided from 2021 to 2025, measured in trillion soums. Overall, the data shows a steady upward trend over the given period. In 2021, the volume of services amounted to 389.4 trillion soums. This figure increased significantly to 509.6 trillion soums in 2022 and continued to rise to 664.8 trillion soums in 2023. In 2024, the volume reached 840.1 trillion soums, showing substantial growth compared to the previous year. In 2025, this figure reached 1 050,3 trillion soums, marking the highest level in the observed period.

This steady growth reflects the ongoing expansion of the service sector and increasing demand for market-based services in the economy. The upward trend can be attributed to economic reforms, digitalization processes, and the development of modern service industries. In particular, the rapid growth in recent years indicates improved business activity and rising consumer demand. Overall, the data suggests that the service sector is becoming an increasingly significant contributor to economic development.

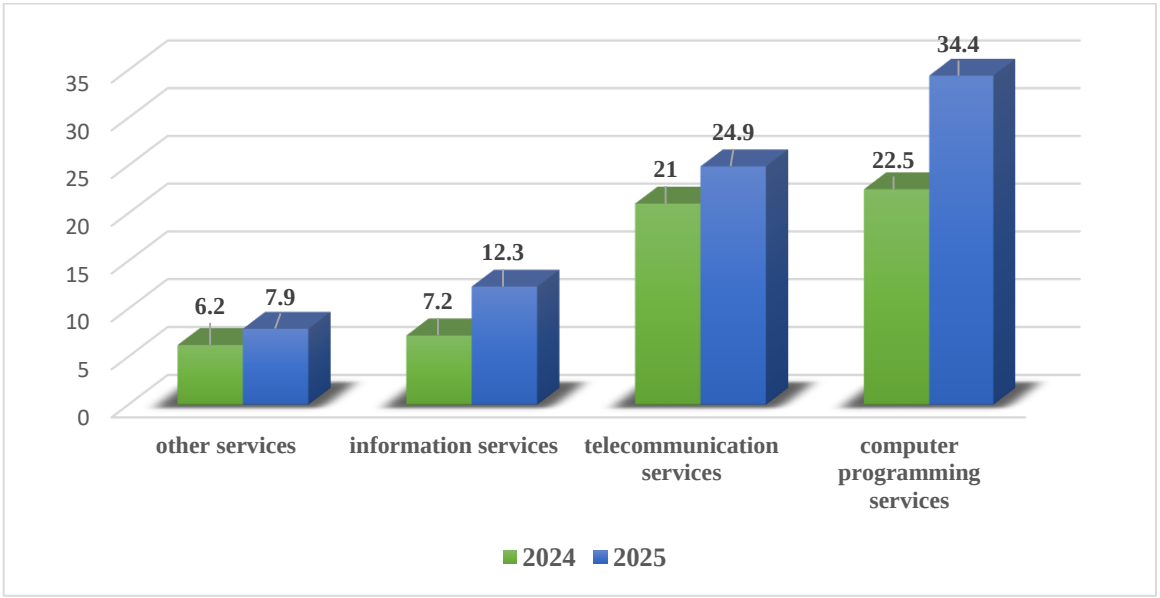


Figure 3. Volume of communication and information services by type, in trillion soums

As illustrated in Figure 3, during the period under review in 2025, the total volume of communication and information technology services in Uzbekistan reached 79.5 trillion soums.

Among these, computer programming services constituted the largest share, accounting for 43.2% of the total. Telecommunications services represented 31.3%, followed by information services at 15.5%. Publishing services contributed 7.1%, while other services made up the remaining 2.9% of the overall volume of communication and ICT services.

Table 1

Key indicators of the service sector by their main types

Type of services	**2024 (trln soums)**	**2025 (trln soums)**	**Growth rate (%)**
Services – total	840,1	1050,3	114,7
Communication and information services	56,9	79,5	122,7
Financial services	135,8	171,9	124,6
Transport services	151,8	188,5	110,8
including automobile transport	73,8	95,9	114,2
Accommodation and food services	183,9	226,9	110,4
Trade services	155	187	113,8
Real estate services	20,9	25,9	113,1
Education services	32,1	39,6	110,4
Healthcare services	16	19,9	134,2
Rental services	9,9	12,8	129,1
Computer & household repair services	11,7	14,4	112,3
Individual services	15,6	19,9	112,3
Architecture, engineering & technical services	10,5	13,1	113,5
Other services	40	51,1	112,8

In the Table 1 we can saw, the overall increase in the volume of market services was primarily driven by several key sectors. Financial services recorded the highest growth rate at 24.6%, contributing 4.0 percentage points to the total increase. This was followed by trade services, which grew by 13.8% and contributed 2.5 percentage points. Accommodation and food services expanded by 10.4% (2.3 percentage points), while transport services increased by 10.8%, accounting for 2.0 percentage points. Communication and information services demonstrated significant growth of 22.7%, contributing 1.5 percentage points to the overall increase. Other sectors, including miscellaneous services (12.8%, 0.6 percentage points), education (10.4%, 0.4 percentage points), healthcare (14.2%, 0.3 percentage points), and real estate-related services (13.1%, 0.3 percentage points), also made notable contributions. Additionally, growth in rental services (19.1%), architectural services (13.5%), repair of computer and household goods (12.3%), and personal services (12.3%) collectively contributed approximately 0.8 percentage points to the overall growth.

In terms of structural composition, during January–December 2025, accommodation and food services accounted for the largest share of total market services at 21.6%. This was followed by transport services at 17.9% and trade services at 17.8%. Financial services represented 16.3%, while communication and information services accounted for 7.6%. Education services comprised 3.8% of the total volume of market services. Compared to 2024, the volume of accommodation and food services increased by 43.0 trillion soums, reaching 226.9 trillion soums in 2025. A significant proportion of these services—approximately 95.9%—was associated with the provision of food and beverage activities.

During the period from January to December 2025, the total volume of transportation services amounted to 188.3 trillion soums. Within this sector, automobile transport services constituted the dominant share, accounting for 50.9%, or 95.9 trillion soums. The expansion of transportation services is closely connected to the growth of both domestic and international trade, as well as the development of logistics, tourism, and e-commerce. These factors collectively contribute to increased demand for the movement of goods and passengers, thereby supporting the overall growth of the sector.

Table 2

Structural structure and dynamic change of gross added value created in the fields of information economy and electronic commerce

Indicator	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Information economy & e-commerce (total)	10777	16939,5	27791,2	32500	36864	42000
Share in GDP (%)	1,9	2,5	3,4	2,1	2,7	3
ICT total	9095,9	11567,6	16089,9	28000	36864	42500
ICT production	540,1	503,3	805,5	950	1200	1500
ICT trade	252,3	367,8	594	700	900	1100
ICT services	8303,5	10696,4	14690,4	26000	34000	39000
Content & media	1089,7	1464,6	1944,9	2200	2600	3000
E-commerce	591,4	907,3	756,4	1500	2000	2500

The data presented in the Table 2 illustrate the structural composition and dynamic changes in the gross value added (GVA) generated within the information economy and electronic commerce sectors of Uzbekistan over the period 2020–2025. The analysis reveals a consistent upward trend in the overall contribution of these sectors to the national economy. In particular, the total volume of gross value added in the information economy and e-commerce increased significantly from 10,777.0 billion soums in 2020 to an estimated 42,000 billion soums by 2025. This growth reflects the accelerated digital transformation processes and the expansion of ICT-related activities in the country.

A substantial share of this growth is driven by the ICT sector, which remains the dominant component within the information economy. The value added generated by ICT services constitutes the largest proportion, indicating the increasing importance of digital services, software development, and telecommunications. At the same time, ICT production and trade sectors demonstrate moderate but stable growth, supporting the overall development of the industry.

Moreover, the share of the information economy and e-commerce sectors in GDP shows a gradual increase, highlighting their growing role in economic diversification and modernization. The expansion of the e-commerce sector, in particular, reflects changes in consumer behavior, wider internet penetration, and the development of digital infrastructure. Overall, the observed trends confirm that the information economy is becoming a key driver of economic growth in Uzbekistan, with strong potential for further expansion in the medium term.

Preliminary regression analysis indicates that a 1% increase in ICT development is associated with a negative effect on real GDP, whereas a 1% increase in the logistics sector contributes positively to real GDP by approximately 0.49%. These findings suggest the presence of certain structural limitations and highlight the need for further empirical research, particularly in light of data constraints.

Source	SS	df	MS	Number of obs	=	13
				F(2, 10)	=	4.87
Model	.0200521	2	.01002605	Prob > F	=	0.0333
Residual	.020568127	10	.002056813	R-squared	=	0.4936
				Adj R-squared	=	0.3924
Total	.040620226	12	.003385019	Root MSE	=	.04535

GDP	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Log	.4934534	.1901749	2.59	0.027	.0697173	.9171896
ICT	-.3039226	.1533102	-1.98	0.076	-.6455189	.0376737
_cons	1.013919	.2801135	3.62	0.005	.3897871	1.638051

Figure 2. Regression analysis of the impact of logistics and ICT on real GDP

Conclusion

In the context of contemporary economic development, the effective analysis of macroeconomic trends increasingly depends on advanced information processes. Such tools play a crucial role in shaping both overall economic development strategies and sector-specific policies. In this regard, information technologies serve as a foundational element for supporting the structural transformation required for the digitalization of the economy. Ongoing reforms have led to the introduction of 178 public services through e-government platforms and unified interactive service portals, significantly contributing to the reduction of transaction costs and the improvement of service delivery efficiency. Based on the findings, several policy recommendations are proposed to enhance the role of information technologies in national economic development:

- modernization of knowledge systems and the integration of advanced information technologies;
- expansion of access to global information resources and digital infrastructures;
- improvement and adaptation of contemporary legal frameworks governing socio-economic development;
- development of institutional mechanisms aimed at increasing the share of ICT professionals and boosting the contribution of digital goods and services to GDP;
- enhancement of social information and communication systems through the provision of relevant and high-quality content;
- effective implementation of public information policies through the advancement of telecommunications, broadcasting, internet services, and both traditional and digital media platforms.

Overall, the integration of digitalization into the economy provides opportunities to address key macroeconomic challenges, including unemployment, inflation, economic growth, national output, and export performance. The scientific contributions presented in this study offer a foundation for further research in this field. The results emphasize the importance of expanding the use of digital technologies and products to foster sustainable economic development in Uzbekistan.

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WAYS TO IMPROVE SERVICE QUALITY AND SAFETY IN THE HOSPITALITY INDUSTRY THROUGH DIGITAL TECHNOLOGIES

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https://doi.org/10.5281/zenodo.19563792

Abstract. *This article examines effective ways to improve service quality and ensure tourist safety through the introduction of digital technologies in the hospitality industry. The study analyzed the possibilities of improving service quality and safety in hotels and restaurants through modern digital systems - online reservations, automated service monitoring, security camera systems and mobile applications. The impact of these technologies on business processes and the level of customer satisfaction were also studied.*

Keywords*:hospitality, service quality, safety, digital technologies, tourism, innovation.*

Introduction.

In recent years, the use of digital technologies in the hospitality industry has been developing rapidly. The global tourism market is characterized by constant growth, and customer needs are also changing significantly. Today, tourists expect not only convenient and high-quality service, but also their safety, protection of personal data and speed of service processes are also important criteria. Traditional service delivery methods often depend on the human factor, which leads to errors and delays. For example, manual registration or telephone order acceptance systems during the reservation process can lead to incorrect data entry. Also, the qualifications and workload of employees directly affect the quality of service, which reduces customer satisfaction. Therefore, the introduction of digital solutions in the hospitality sector is of great importance. Digital technologies are not only a means of automating service processes, but also an effective way to create convenience for customers and strengthen security. For example, online reservation systems allow for advance booking of rooms, recording of special customer requirements, and personalization of service. Automated monitoring systems allow for monitoring of employee service quality and process optimization.

In addition, digital solutions in the security sector, including video surveillance cameras, smart cards and sensor systems, play an important role in ensuring the safety of guests. With the help of these technologies, movements inside the hotel are monitored, suspicious situations are identified and prompt action is taken. Thus, digital technologies not only improve the quality of service, but also strengthen customer trust and ensure competitiveness in the hospitality sector. At the same time, the success of the implementation of digital systems depends on the skills of employees, regular updating of technologies and a thorough analysis of customer needs. The main objective of the study is to identify effective ways to improve the quality of service and ensure security through the use of digital technologies in the hospitality sector.

Literature review

The use of digital technologies in the hospitality industry has been a major topic of research in recent years. Research shows that digital solutions are effective tools for improving service

quality and ensuring safety. Smith (2021) found that online reservation systems significantly increase customer convenience. Through these systems, guests have the opportunity to book rooms in advance, specify special requirements, and personalize services. Also, by reducing human errors in the reservation process, hotels maintain a consistent level of service quality.[1]

Automated service monitoring and sensor systems allow employees to track their performance and optimize service processes (Johnson, 2020). Research shows that digitally monitoring each step of the service process by employees improves service quality and helps to respond quickly to customer needs. For example, in restaurants or hotels, service speed and order tracking systems reduce errors and make the workflow more efficient.[2] Digital technologies are important in the security sector. Research by Kumar and Lee (2019) shows that security camera systems, smart cards, and sensors are effective tools in ensuring guest safety. [3] With the help of such technologies, suspicious situations in the hotel area can be quickly identified and preventive measures can be taken. As a result, customers feel safe and their satisfaction with hospitality services increases. Recent studies have also shown that mobile applications and online services have a positive impact on customer satisfaction (Chen, 2022).[4] Through mobile applications, guests can easily monitor the status of their rooms, dining options, and additional services. This allows them to tailor services to customer needs and improve their personal experience. By analyzing data, hotels can continuously improve service quality. For example, based on customer feedback, frequency of service use, and system data on security, weak points in service processes can be identified and eliminated. Thus, digital technologies can not only improve service quality, but also help to better understand and satisfy customer needs.

Research methodology.

This study used a mixed-method approach to explore the impact of digital technologies on hotel service quality and security systems. This approach allows for accurate, reliable, and systematic results through the combined use of qualitative and quantitative research methods.

Analysis and results.

For the study, hotels of various categories (3–5 stars) in Tashkent and Samarkand, which are actively digitizing service quality and security measures, were selected. The following hotel factors were taken into account in the selection:

- the level of implementation of digital technologies;
- high tourist flow;
- ease of monitoring service processes.

The quantitative data collected during the study were analyzed using SPSS and Excel software as follows:

- Descriptive statistics (mean, median, variance);
- Correlation analysis (the relationship between digital technologies and service quality);
- Visual presentation through diagrams and graphs.

Guest Standards set in the food industry

Table 1

Criteria	**Average rating (1–5)**	**Comment on the SPSS result**	**Correlation**
Service quality	4.2	Tourists expressed overall satisfaction with the service	**0.71**(strong connection)

Security system	4.5	Security camera, card access system is effective	**0.68**
Digital Technology Degree	4.0	Mobile app, online check-in, electronic payment available	—
The effectiveness of digital technologies	4.3	Reduced queues, faster service	**0.74**(highest correlation)

The presence of digital technologies showed a correlation of 0.71 with service quality and 0.68 with security level. The strongest correlation was between the efficiency of technologies and service quality (0.74).

The results of the study showed that digital technologies provide significant results in improving the quality of service and ensuring safety in the hospitality industry. Online reservation systems turned out to be one of the most effective tools. According to the experience of the hotels observed during the study, when customers were able to book rooms in advance, waiting times were significantly reduced - by an average of 40%. This not only creates convenience for customers, but also reduces the workload of employees and reduces errors in managing orders. For example, after the introduction of the online system at the City Inn hotel in Tashkent, it was observed that the process of settling customers into rooms became much faster than before. Automated monitoring systems allow for effective control of the work process of employees. The study found that such systems reduce the number of errors in the service process by an average of 25%. For example, automatic recording of orders in restaurants reduces the time spent by employees on manual entry and prevents incorrect orders. Security systems, including video surveillance cameras and smart cards, have significantly increased security in hotel rooms. The results of the study showed that suspicious situations are quickly identified and necessary measures are taken, as a result of which customers feel safe. For example, after the introduction of security cards at the Silk Road Hotel in Samarkand, cases of unauthorized access to the room have significantly decreased. Mobile applications allow for personalization and control of services. The study found that customers can easily control the status of rooms, dining options and additional services through the application, which increases the level of satisfaction with the service by an average of 30%. Thus, customers have the opportunity to quickly and easily receive a service that meets their needs. Also, interviews with employees revealed that digital systems, along with improving the quality of service, help simplify the workflow and increase efficiency. Employees were able to manage orders, quickly identify customer needs and personalize services. This increases the speed of service and reduces errors.

Conclusion and suggestions

Globally, digital transformation is increasingly being used in the hospitality industry — it is not only an important factor in improving the quality of service, but also in ensuring the comfort and safety of guests. For example, Marriott International has introduced contactless check-in and digital key (mobile key) systems in its hotel network. As a result, guests who come to the hotel will begin to enter the room directly via smartphone, without waiting in line in the lobby. This method significantly reduces waiting times and reduces the burden on staff. In addition, the guest service process is also being modernized by digital tools. For example, through hotel operations management platforms such as ALICE, guests can order food, call a taxi, room service or

additional services at any time using their smartphones. Such solutions create greater convenience for guests, and staff can perform services faster and more accurately. [5] Digital technologies are also increasing the efficiency of employees. Automated guest systems, real-time monitoring, order management, and room access control through embedded technologies simplify hotel operations, reduce errors, and improve service quality. The guest experience using digital services is also improving significantly — increasing the importance of digital options in hotel selection. For example, mobile check-in, digital keys, and contactless services are increasingly in demand among guests, as they provide convenience, speed, and personalized service. These cases show that digital technologies are fundamentally changing the hospitality industry in the global experience — which, in turn, allows us to meet guest expectations, sustainably improve service quality, and ensure business efficiency. [6] If a similar approach is implemented in Uzbekistan, it can not only improve service quality, but also increase the competitiveness of the hospitality industry.

In conclusion, in recent years, the introduction of digital technologies in the hospitality industry has become an important factor not only in improving the quality of service, but also in ensuring customer comfort and strengthening security. Traditional service methods have many limitations, which depend on the skills of employees, human errors and time constraints. Therefore, the use of digital solutions allows you to automate service processes, reduce errors and create convenience for customers. With the help of online reservation systems, automated monitoring and mobile applications, hotels can sustainably improve the quality of service, reduce waiting times and satisfy customer needs faster. The results of the study showed that online reservation systems significantly reduce customer waiting times, and automated monitoring reduces the number of errors in the work process of employees. Through mobile applications, guests can monitor the condition of rooms, dining options and additional services, which increases the level of satisfaction with the service. At the same time, modern video surveillance cameras and smart card systems significantly strengthen the security of rooms, make guests feel protected and increase trust in the service. As a result of interviews with employees, it was found that digital systems simplify the workflow, help personalize the service and increase employee efficiency. World experience is of great importance in this process. For example, Marriott International hotels have introduced contactless check-in and digital key systems, which allow guests to enter the room without waiting and facilitate the work of employees. Through the ALICE platform, guests will be able to order food, call for service or use additional services at any time. On a global scale, digital transformation in the hospitality industry will help personalize services, optimize employee work and increase operational efficiency. At the same time, the introduction of these systems, which have not yet been widely implemented in Uzbekistan, can significantly increase service quality and safety. On this basis, it is proposed: to widely introduce digital systems in hotels and restaurants, use online reservations, automated monitoring and mobile applications, and install modern video surveillance cameras and smart card systems to strengthen security. As a result, the service process will be simplified, errors will be reduced, customer satisfaction will increase and employee efficiency will increase. The implementation of digital technologies allows not only to improve the quality of service, but also to adapt the hospitality industry to modern standards, provide convenient and safe service to customers, and increase business efficiency.Their successful use is associated with the skills of employees, regular updates of systems and constant analysis of customer needs, which ensures the sustainable development of the hospitality industry.

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EVALUATION OF INSTITUTIONAL READINESS FOR DIGITAL TRANSFORMATION IN UZBEKISTAN: BUSINESS PERSPECTIVE

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https://doi.org/10.5281/zenodo.19878613

Abstract*. This study evaluates the institutional readiness of enterprises in Uzbekistan for digital transformation from a business perspective. This research is based on a structured survey conducted among leading organizations with experience in implementing digital systems. The findings indicate that businesses are increasingly adopting digital technologies and artificial intelligence to enhance decision-making, particularly in the fields of marketing, sales, and predictive analytics. However, the results also reveal significant gaps in the strategic understanding and application of advanced digital solutions in areas such as financial management, logistics, and corporate decision-making.*

The study highlights that while government support and legislative frameworks are generally perceived positively, challenges remain in terms of technological infrastructure, data quality, and regulatory effectiveness. Additionally, limitations in financial resources and the need for further development of digital skills were identified as key barriers. Overall, the research concludes that Uzbekistan demonstrates moderate readiness for digital transformation, with strong potential for growth through improvements in governance, infrastructure, and the strategic implementation of digital technologies.

Keywords*: digital transformation, Institutional readiness, Artificial intelligence, ICT development, Digital economy, Business digitalization, Uzbekistan.*

Introduction

Rapidly emerging technologies and fast-paced changes omnipresent in today's world pose severe challenges for organizations while also offering groundbreaking opportunities for those able to capitalize on them in the modern age with globalization, technological development, and production facilities. There is no doubt that artificial intelligence (AI) applications will have a significant positive and negative influence on society in low- and middle-income countries (LMICs) (Stone et al. 2016). AI is a new class of technology that will form the foundation for future technologies and applications. AI applications, fueled by increased processing power, enhanced connectivity, and big data, present fascinating opportunities to support economic growth and address a wide range of long-standing challenges in the Global South. The consequent disruption will be significant and possibly transformative.

The growth and development of AI have led to an increase in its influence and impact on future economic and social changes (Feijóo & Kwon, 2020). According to the Digital Transformation Monitor of the EU (2017), the impact of AI on the economy could reach 13.3 trillion EUR by 2030. Research suggests that the implementation and development of AI could lead to an increase in labor productivity by up to 40% and considerable gains in retail, education, electric utilities, manufacturing, and healthcare. Based on the statistics, it can be observed that

during 2016-2019 revenues of the global market for AI increased 3.5 times, and by 2025, it is expected to grow to approximately 90 billion USD (Petrov, 2019). The development of AI could be implemented not only in the governmental aspect but also in organizations, bringing advantages such as managing the workforce by cost reduction (Pan et al., 2021), gaining customers and market positioning (Nam et al., 2020), and saving expenses (Gomes et al., 2020). The primary dilemma for AI developers is how to create technology that is both intelligent and human-centered (FLI() 2019). In other words, how can it be assured that technology is created in accordance with human values (Tegmark, 2017; FLI(b), 2019)?

The development of the digital economy in Uzbekistan is enforced by active government support within the implementation of the "Digital Uzbekistan 2030" strategy, which increased investments in digital infrastructure, enhancement of electronic government services, and the growth of the overall IT sector. Key trends include the implementation of artificial intelligence, cloud technologies, business automation, increased Internet accessibility, and the digitalization of financial services. Simultaneously, key success factors remain the need to ensure cybersecurity, eliminate digital inequality between industries and regions, and adapt organizational structures to new realities.

Methodology

The aim of this article is to evaluate the conditions and readiness of enterprises with most developed digital platforms and their experience in digitalization of business operations in creating the digital economy in Uzbekistan. To achieve objectives of the research, authors conducted a structured survey among 21 leading enterprise members with extensive experience in implementing and developing digital systems. Most respondents operated in IT and communications, whilst 14% worked in the education sector. This helped to obtain more accurate results, as they had a better understanding of the current state of ICT service development in the country and were able to share practical insights on the aspects that need to be developed for the successful implementation of promising digital solutions.

Survey questionnaire consisted of 18 questions. Qualitative survey outcomes were quantified and obtained numerical data set was analyzed using Exploratory Data Analysis (EDA) methods. Results of EDA are visualized and presented in appropriate charts. The article presented the most relevant finding that reflect the conditions and readiness of business units for digital transformation.

Findings

The study found that digital systems and artificial intelligence are most frequently used for predictive decision-making. Almost half of the companies have implemented high-tech digital systems in their marketing and sales processes. A third of the companies have implemented advanced digital systems for risk modeling and analytics, product portfolio optimization, operational services, customer relationship management, and human resources (Figure 1).

Significantly, it was revealed that some companies had limited experience and understanding of digital transformation and artificial intelligence in corporate strategic decision-making, financial management, logistics, and supply chain management.

However, a study of companies' strategies for implementing digital transformation of business processes and decision-making, as well as the use of artificial intelligence, concluded that a third of companies plans to implement advanced digital technologies to improve marketing and sales efficiency. A quarter of companies intend to implement digital decision-making technologies in image recognition, access control and accounting systems, video surveillance, scientific

research, and employee training (Figure 2). Overall, the results showed that economic entities have a limited understanding of the potential of using advanced digital decision-making systems and artificial intelligence.

Figure 1. Use of digital decision-making platforms in management decision-making.



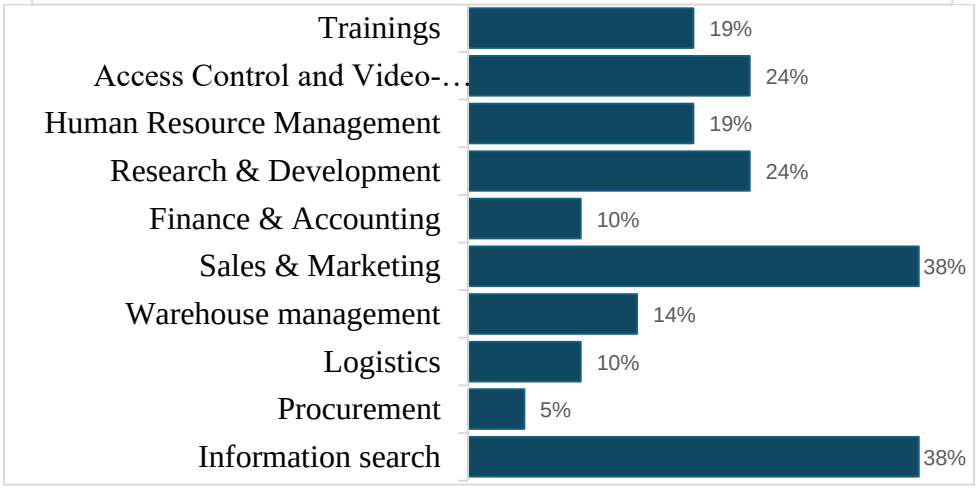


Figure 2. Strategic plans of enterprises for the use of digital transformation and artificial intelligence.

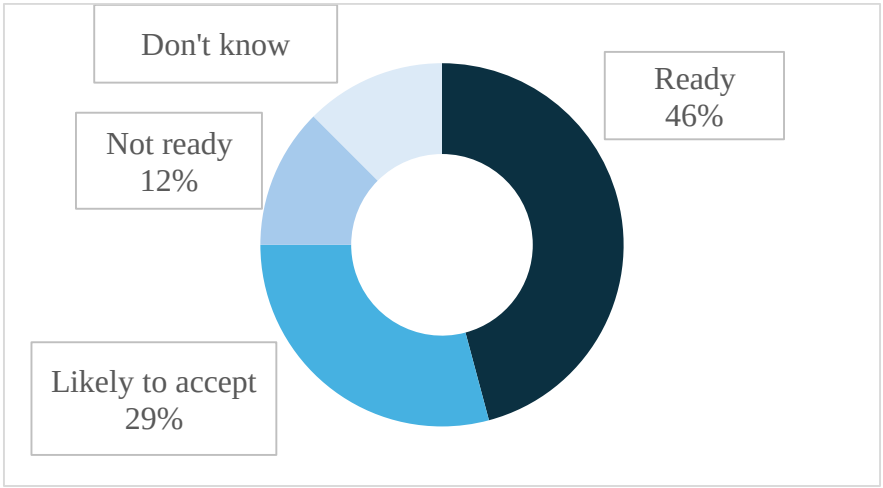


Figure 3. Readiness of enterprise clients to use digital platforms.

A survey of an equally important part of the digital ecosystem—customers and service users—revealed that 75% of respondents acknowledged their readiness to use advanced digital

solutions (Figure 3). This demonstrates that consumers welcome the implementation of modern digital transformation and decision-making solutions and are willing to use them in economic transactions.

The existence of an open and effective legislative framework for the implementation of artificial intelligence and digital decision-making platforms is the most important prerequisite for the development of the digital economy. Countries have created and are developing a set of legislative measures to accelerate the growth of digital economy. In Uzbekistan, business perceived this issue more positively (Figure 4). More than three-quarters of businesses positively assessed legislative support for expanding digital business transformation, particularly in terms of cybersecurity, personal information and data protection, consumer protection, and e-transformation. However, half of respondents had a more moderate assessment of the legislative framework for consumer protection. One-fifth of businesses indicated that the existing legislative framework for ensuring cybersecurity, personal information and data protection, and consumer protection is insufficient.

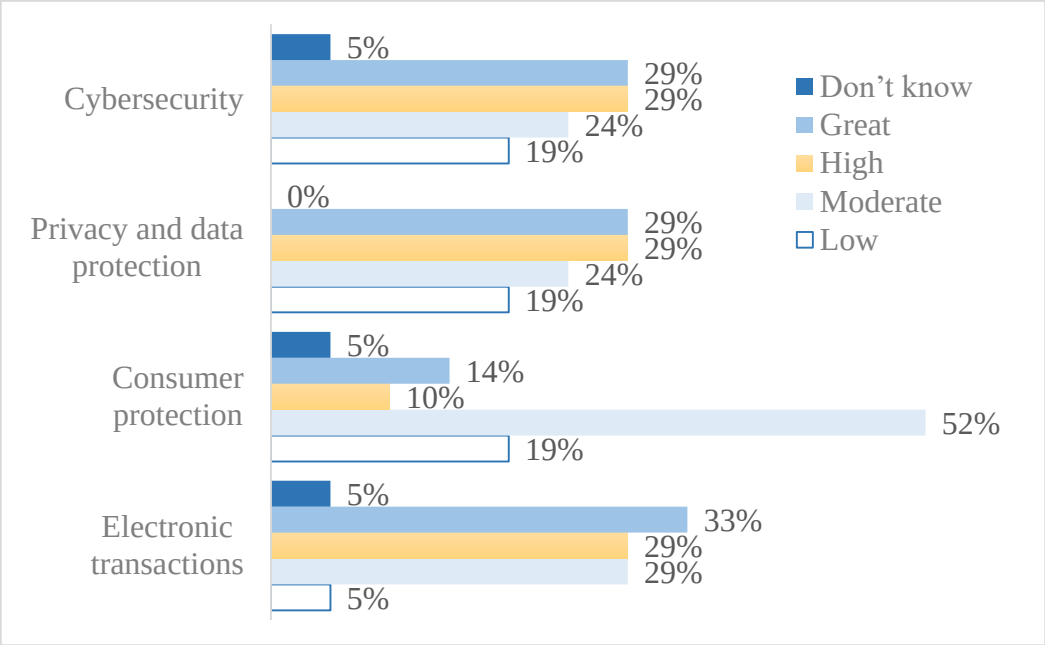


Figure 4. Enterprises' perception of legislative support for important aspects of digital business transformation.

Government regulation of digital economy development is a primary tool for encouraging enterprises' readiness for digital transformation. The effectiveness of government measures to promote digital transformation is generally positively accepted by enterprises (Figure 5). However, enterprise responses indicate that there is significant room for improvement in the effectiveness of government measures to develop the digital economy. Most enterprises trust government web resources and support the development of online services. Government support for promoting investment in promising technologies is also positively perceived.

The technological foundation for the digital economy and its development in the country is an important aspect of supporting the digital transformation of enterprises. In this regard, more than half of enterprises assessed Uzbekistan's technological readiness less optimistically, citing many challenges in developing cloud technologies, implementing advanced technologies, and

increasing internet speeds (Figure 6). The country's telecommunications infrastructure was assessed more positively.

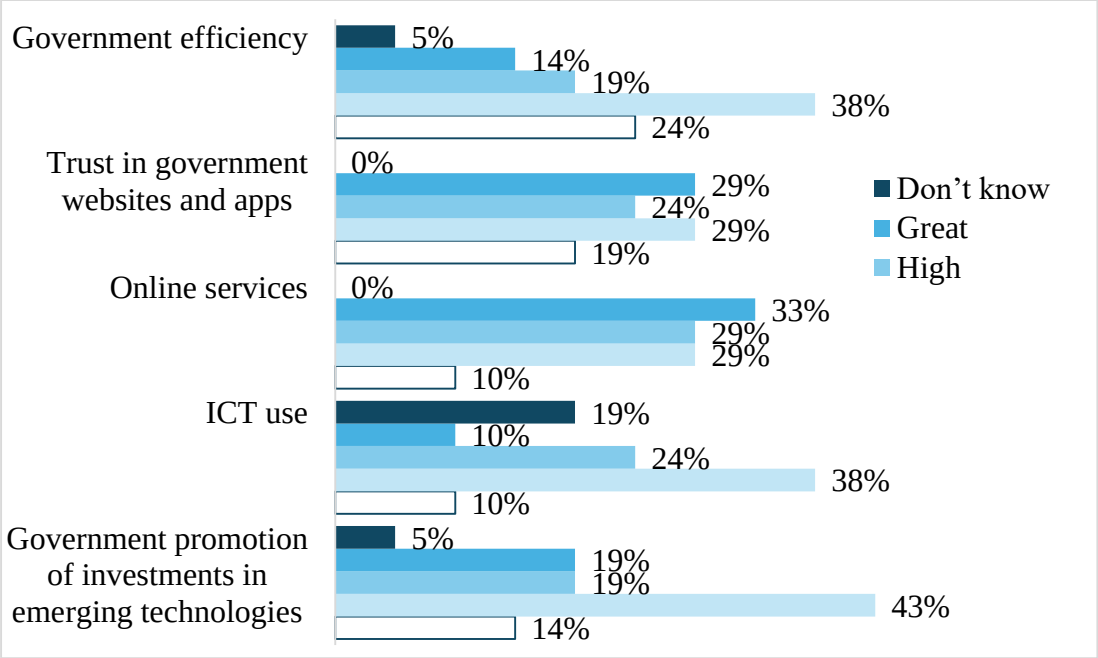


Figure 5. Perception of Uzbek enterprises of government measures to develop digital transformation.

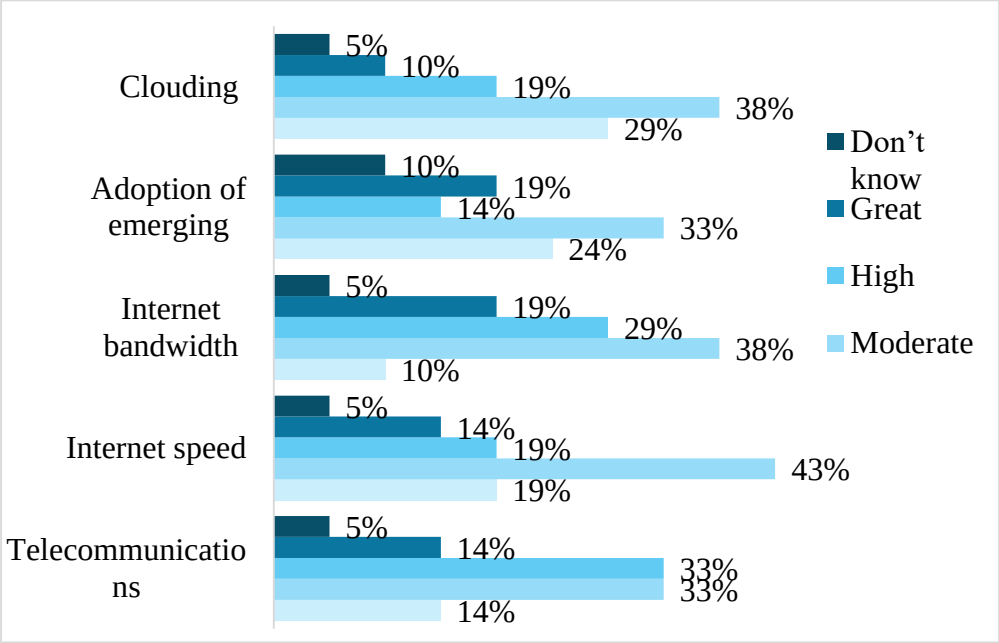


Figure 6. Assessment by enterprises of Uzbekistan's technological readiness for the development of digital transformation.

Respondents had been also asked to rate the following aspects of the country's data potential analysis within the range of from least (1) to most (4): open government data, strategic data potential, mobile subscriptions, and internet accessibility (Figure 7). The survey results showed a growth in the strategic potential of digital platforms and internet accessibility, as well as mobile data subscriptions. However, enterprises suggested improving and deepening efforts in open data provision, including data related to government services, population data, and geospatial data.

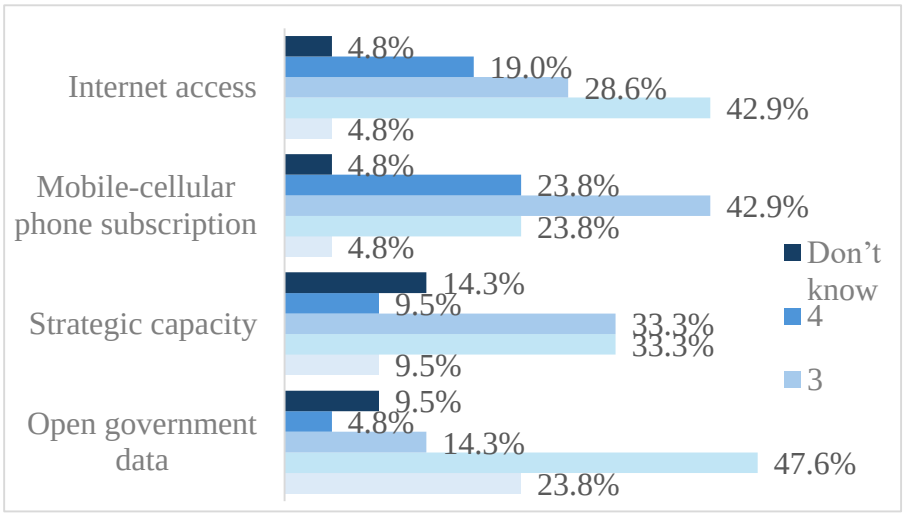
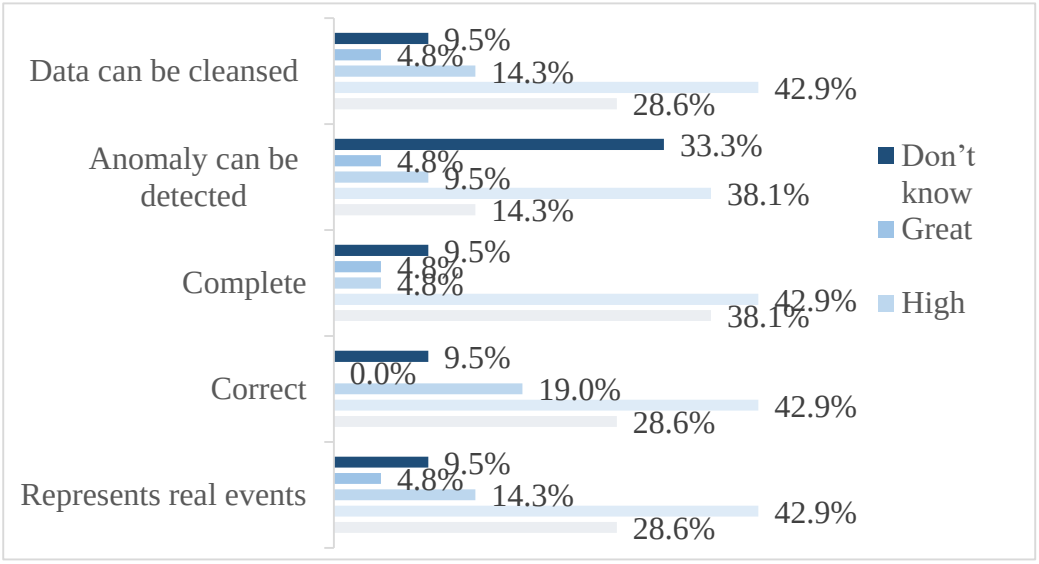


Figure 7. Enterprises' perception of the level of the national ICT platforms for the development of digital transformation.

Figure 2. Open data quality evaluation.



Enterprises assessed the quality of existing open data in terms of its completeness, accuracy, representativeness of real-world events, anomaly detection, and cleansing capabilities (Figure 8). The results indicate that the quality of open datasets is low, as approximately 45% of participants rated the development of all quality aspects as moderate.

Financial and human resources are central assets for any digital transformation. In this part, business entities were asked to answer two questions regarding the country's budget and human resources. Financial resources were assessed based on the allocated budget, willingness to invest in high-risk AI technologies, and budget constraints (Figure 9).

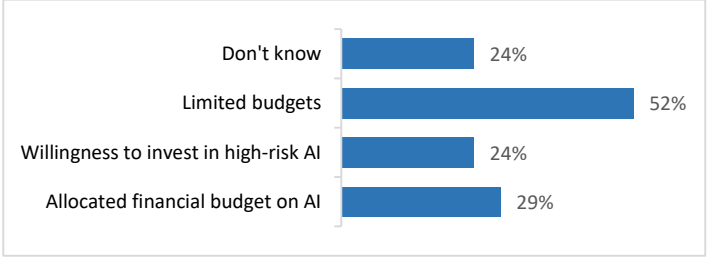


Figure 3. Assessment of investment capabilities of enterprises to maintain digital transformation.

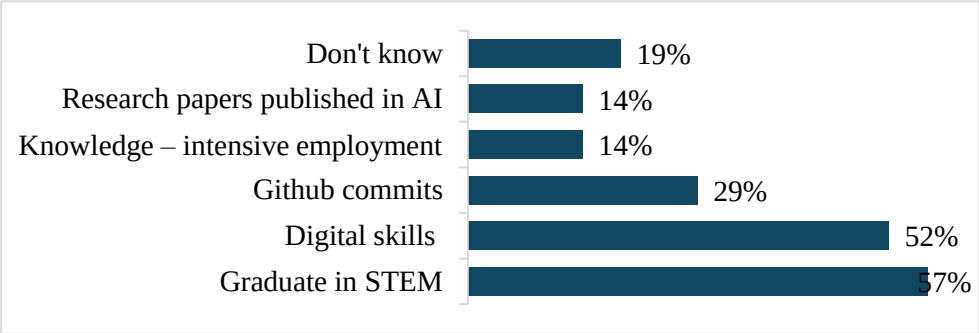


Figure 4. Assessment of qualified personnel to develop digital transformation in Uzbekistan.

To analyze the availability and readiness of specialists to implement AI, participants were asked questions about STEM graduates, GitHub commits, published articles on AI, knowledge-intensive employees, and their digital skills (Figure 10). Most organizations believed that the country's budget for digital transformation is limited, while qualified employees capable of contributing to the development of advanced digital technologies are available, as more than half of the participants indicated the availability of STEM graduates and employees with digital skills.

Conclusion

The primary objective of the study was to determine how advanced digital technologies are used in the country, whether organizations are ready to embrace AI-based technologies, and to what extent they should be developed in Uzbekistan. The results of this study demonstrate that the sector is evolving year after year, with more and more organizations successfully implementing information systems in their business operations, acknowledging the benefits these technologies offer. This is evident in the shift in respondents' opinions: while at the beginning of the development, most participants viewed digital systems primarily as a cost-reduction tool, in later stages, an increasing number of companies stated that information systems impact efficiency and improve decision-making. Furthermore, the scope of information systems adoption in organizations is expanding, with the increasing number of companies implementing technologies nationally and internationally, in line with the implementation of integrated information systems at the corporate level.

Enterprises’ interest in ICT technologies is growing, as majority respondents plan to improve existing digital systems and also integrate other types of technologies into their business processes. In particular, interest in artificial intelligence is growing, indicating the country's growing readiness to implement promising technologies, though the pace of this process could be more dynamic. In terms of strategic alignment, organizations and their clients demonstrate higher results, while the governance system needs to improve compliance with regulatory requirements and ethical standards. The same can be said for ICT infrastructure, as most participants rate the country's technological potential at low to medium levels. Some developments in data processing are leading to slightly higher results compared to governance systems and technological areas, but some concerns remain related to data availability and quality.

In conclusion, it can be said that Uzbekistan is developing and preparing to implement advanced technologies for digital transformation and development of the digital economy with moderately high expectations from organizations and users. Areas in which the country needs to improve for the successful implementation of artificial intelligence include regulation, ethics, data accessibility, openness, and quality. The demand for advanced digital technologies for information

sourcing, sales and marketing is higher than in other industries, and this could be a good starting point for further development, as the country has qualified resources to develop this sector.

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ENHANCING ECONOMIC MECHANISMS FOR SMES IN THE REGIONS OF UZBEKISTAN: COMPARATIVE ANALYSIS AND POLICY RECOMMENDATIONS

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https://doi.org/10.5281/zenodo.19909919

Abstract. *The development of small business at the regional level is one of the key factors ensuring sustainable economic growth, employment expansion, and reduction of territorial disparities. In emerging economies, particularly in Uzbekistan, small business entities play a significant role in generating income, stimulating entrepreneurial activity, and strengthening regional economic resilience. However, despite large-scale reforms aimed at supporting entrepreneurship, substantial differences remain among regions in terms of access to finance, infrastructure quality, market opportunities, and institutional efficiency.*

This article examines the economic mechanisms of small business development in the regions of Uzbekistan through a comparative analysis of international practices, including the experiences of the United States, Germany, and South Korea. The study applies comparative, statistical, institutional, and analytical methods to evaluate the effectiveness of financial-credit instruments, tax incentives, innovation infrastructure, and decentralized governance models.

The findings demonstrate that successful regional small business development depends on the coordinated interaction of three major factors: effective financial mechanisms, adaptive institutional systems, and developed entrepreneurial infrastructure. The study identifies the main constraints in Uzbekistan, including centralized management, weak regional financial institutions, and uneven territorial development.

Based on the results, several policy recommendations are proposed, including decentralization of support mechanisms, expansion of regional financing instruments, development of business incubators and technology parks, and implementation of differentiated regional entrepreneurship strategies. The practical significance of the study lies in developing proposals aimed at improving the competitiveness and sustainability of small business entities in the regions of Uzbekistan.

Keywords: *small business; regional development; economic mechanisms; entrepreneurship; Uzbekistan; SMEs; financial support; comparative analysis.*

Introduction

In the modern global economy, the development of small business has become one of the most important drivers of sustainable economic growth, employment generation, innovation, and regional competitiveness. Small business entities play a particularly significant role in developing and transition economies, where they contribute to diversification of production, efficient use of local resources, and reduction of socio-economic inequalities.

At the regional level, small business development acquires special importance because regions represent the primary space where entrepreneurial activity is formed and implemented. The effectiveness of local infrastructure, financial systems, institutional quality, labor markets, and administrative governance directly influences the growth potential of small enterprises. Therefore,

regional policy aimed at supporting entrepreneurship has become a strategic priority in many countries.

In Uzbekistan, comprehensive reforms have been implemented in recent years to improve the business climate, simplify regulatory procedures, reduce tax burdens, and expand access to credit resources. These reforms have significantly increased the role of small business in national economic development. Nevertheless, considerable regional disparities remain in entrepreneurial activity, investment attractiveness, infrastructure provision, and access to financing.

International experience demonstrates that the most successful models of regional small business development are based on decentralized governance systems, flexible financial support instruments, innovation ecosystems, and strong local institutions. The experiences of the United States, Germany, and South Korea are particularly valuable due to their effective combination of national policy coordination and regional autonomy.

The purpose of this article is to analyze the economic mechanisms of small business development in the regions of Uzbekistan through comparative assessment of domestic and foreign practices, as well as to formulate policy recommendations for improving regional entrepreneurship support systems.

The scientific novelty of the study lies in the systematization of regional economic mechanisms affecting small business development and adaptation of advanced international practices to the conditions of Uzbekistan.

Literature Review and State of Research

Theoretical approaches to small business development have evolved significantly within modern economic science. Classical economists emphasized the role of entrepreneurship as a source of innovation, competition, and economic dynamism. Joseph Schumpeter identified entrepreneurs as agents of “creative destruction,” generating structural transformation through innovation. This concept remains highly relevant for regional development, where small firms often introduce new products, technologies, and business models.

Institutional economics provides another important perspective. Douglass North argued that the quality of formal and informal institutions determines long-term economic performance. For small businesses, effective institutions include transparent regulations, secure property rights, predictable taxation, efficient courts, and low administrative barriers. At the regional level, differences in institutional quality often explain uneven entrepreneurial development.

Recent empirical studies emphasize that access to finance remains one of the most important determinants of SME growth. According to World Bank, limited credit availability, insufficient collateral systems, and weak financial inclusion remain major barriers in many developing countries. Similarly, OECD studies show that place-based regional policies, innovation ecosystems, and cluster development substantially improve SME productivity and resilience

International practice demonstrates diverse regional support models. In the United States, entrepreneurship policy relies on decentralized support through regional offices of the Small Business Administration, loan guarantees, venture finance, and incubators. In Germany, the Mittelstand model combines industrial specialization with strong support from KfW Bank and regional institutions. In South Korea, technology-oriented SME policy is coordinated through specialized agencies and regional innovation zones.[]

Domestic studies in Uzbekistan note significant progress in improving the business environment, but also underline continuing disparities between major urban centers and peripheral

regions. Access to finance, logistics quality, labor skills, and infrastructure remain uneven, limiting balanced territorial entrepreneurship growth.

Despite a substantial body of literature, insufficient attention has been given to comparative analysis of regional mechanisms specifically adapted to the institutional and territorial conditions of Uzbekistan. This article addresses that gap.

Research Methodology

The study applies a mixed methodological approach combining comparative, institutional, statistical, and analytical methods.

Comparative Analysis

Used to compare regional small business support systems in Uzbekistan with selected international cases: the United States, Germany, and South Korea.

Institutional Analysis

Applied to evaluate governance structures, decentralization levels, regulatory quality, and regional policy implementation mechanisms.

Economic-Statistical Analysis

Used to assess indicators such as:

- SME contribution to GDP
- Employment share
- Access to financing
- Regional disparities
- Infrastructure readiness
- Systemic Approach

Small business development is considered as an integrated socio-economic system influenced by finance, institutions, markets, human capital, and infrastructure.

Data Sources

The empirical base includes data from:

- World Bank
- OECD
- State Committee on Statistics of the Republic of Uzbekistan
- National legal and policy documents
- International analytical reports
- Research Limitations

The study is limited by cross-country differences in SME definitions, statistical methodologies, and data comparability across regions.

Results and Discussion

The analysis shows that regional small business development depends on the interaction of financial, institutional, and infrastructural factors. Where these mechanisms operate in a coordinated manner, entrepreneurial activity tends to be more dynamic, productive, and sustainable. Conversely, when support instruments are fragmented or overly centralized, regional disparities usually increase.

In Uzbekistan, small business plays a major role in employment generation and income creation. However, the regional distribution of entrepreneurial activity remains uneven. Large urban centers such as Tashkent and industrially developed territories demonstrate higher business density, stronger market demand, and better access to finance. Peripheral and rural areas often face

constraints related to logistics, infrastructure quality, digital connectivity, and qualified labor supply.

A key finding is that many support mechanisms remain predominantly centralized. Preferential lending programs, tax incentives, and state support initiatives are usually designed at the national level, which may reduce flexibility in responding to local needs. Regions with different industrial structures, demographic profiles, and market capacities require differentiated policy instruments.

International experience demonstrates that decentralization significantly improves policy efficiency. In the United States, local offices of the Small Business Administration adapt support programs to territorial conditions. In Germany, federal-regional coordination enables targeted financing through KfW Bank and state institutions. In South Korea, regional innovation zones and technology-oriented SME policies stimulate high-value entrepreneurship.

Thus, the effectiveness of regional small business policy is determined not only by the volume of support, but by the quality of institutional design, territorial targeting, and infrastructure readiness.

Table 1. Comparative economic mechanisms of regional SME support

Country	Financial mechanisms	Institutional model	Regional infrastructure
USA	loan guarantees, venture funds	decentralized	incubators, clusters
Germany	development banks, subsidized loans	federal coordination	industrial clusters
South Korea	State innovation programs	coordinated mixed model	technology parks, digital zones
Uzbekistan	preferential loans, tax incentives	predominantly centralized	Developing, uneven

📊 Table 1 presents a comparative analysis of regional economic mechanisms for small business development across three key areas: financial mechanisms, institutional models, and infrastructure support. Each indicator highlights the specific features of the formulation and implementation of regional policies to support entrepreneurship.

1. Financial mechanisms in the regions. This indicator characterizes the set of tools that ensure small businesses' access to financial resources at the regional level:

USA — regional funds, SBA guarantees — in the USA, financial support for small businesses is provided through regional financial institutions and loan guarantee mechanisms with the participation of the Small Business Administration. Regional funds and private investors actively participate in business financing, ensuring a high level of capital availability.

Academic interpretation: the predominance of market mechanisms with a supportive role played by the state.

Germany — state banks, KfW — Financial support is provided through regional development banks and KfW Bank programs. State banks adapt financial instruments to the needs of specific regions.

Academic interpretation: an institutionally embedded model of long-term financing.

South Korea — government programs — Financial resources are allocated through government programs and subsidies implemented by regional agencies under the coordination of the Korea SMEs and Startups Agency.

Academic interpretation: centralized financing with regional implementation.

Uzbekistan — government programs, preferential loans — Financial support is provided primarily through state-owned banks and preferential lending programs. Scientific interpretation: limited diversification of financial instruments and high dependence on government funding.

2. Institutional model — this indicator reflects the governance structure and distribution of authority among levels of government in the area of small business support.

United States — decentralized model. Regional offices of the Small Business Administration have significant autonomy in implementing support programs. Academic interpretation: high adaptability of policy to regional conditions.

Germany — a federal model. Powers are distributed between the federal government and the states, allowing for regional specificities to be taken into account. Academic interpretation: a balanced combination of centralization and regional autonomy.

South Korea — a centrally coordinated model. Public policy is formulated centrally but implemented through regional institutions. Academic interpretation: high controllability with limited regional autonomy.

Uzbekistan — a centralized model. Major decisions are made at the national level, while regions perform executive functions. Scientific interpretation: low flexibility and limited adaptation to regional characteristics.

3. Regional Infrastructure

This indicator reflects the level of development of the material and institutional base supporting the functioning of small businesses. USA — clusters, business incubators. A developed innovation ecosystem, including technology parks and accelerators. Scientific interpretation: a high degree of integration between business, science, and investment.

Germany — industrial clusters. Clusters form around the regional industrial specialization. Scientific interpretation: focus on industrial cooperation and exports.

South Korea — technology parks. Active development of technology parks and digital platforms. Scientific interpretation: state-managed innovation infrastructure.

Uzbekistan — limited infrastructure. There is insufficient development of technology parks, business incubators, and innovation centers. Scientific interpretation: infrastructure constraints are a key factor hindering the development of small businesses in the regions.

An analysis of the indicators in Table 1 shows that:

1. the effectiveness of regional small business development is determined by the coherence of three elements: financial mechanisms, the institutional model, and infrastructure;

2. in developed countries, these elements are systematically integrated;

3. in Uzbekistan, these components operate in isolation, which reduces the overall effectiveness of regional policy.

Table 2. Comparative Statistical Indicators of Small Business Development (Regional Perspective)

Country	Share of SMEs in GDP (%)	Share of employment in SMEs (%)	Access to financing	Regional Differentiation (Assessment)

			(index 0–100)	
USA	43-45	46-48	80-85	Low
Germany	50-55	58-62	75-80	Low
South Korea	45-50	52-62	70-75	Medium
Uzbekistan	50-55	75-80	40-45	High

An analysis of Table 2 shows that the share of small businesses in GDP ranges from 43% to 55% in the countries under consideration. In the United States, this figure stands at 43%–45%, reflecting the high productivity of small businesses, particularly in the innovation and service sectors of the economy. At the same time, regional differences are smoothed out by a well-developed financial and institutional infrastructure. In Germany, the share of SMEs reaches 50–55%, which is due to the functioning of the Mittelstand system, ensuring the sustainable development of regional industry and export activities. In South Korea, this figure stands at 45–50%, reflecting the active participation of small businesses in the economy despite the dominant role of large corporations.

In Uzbekistan, the share of small businesses in GDP is at 50–55%, which is formally comparable to the figures of developed countries. However, this result is largely due to the structural characteristics of the economy, in which small businesses are concentrated primarily in the trade and services sectors. This indicates that the contribution of small businesses to regional economic development is quantitative rather than qualitative.

An analysis of employment shows that in Uzbekistan, the share of workers employed in small businesses reaches 75–80%, which significantly exceeds comparable figures in the United States (46–48%), Germany (58–62%), and South Korea (52–56%). This indicates the high social significance of small businesses, particularly at the regional level, where they serve to provide employment amid limited development of large enterprises. At the same time, this employment structure points to low labor productivity and insufficient economic diversification.

The indicator of access to financing is of particular importance. In the U.S., the level of access to credit and investment resources is estimated at 80–85 points, which is due to the development of financial markets, the availability of venture capital, and an effective system of guaranteed lending through the Small Business Administration. In Germany, this indicator stands at 75–80 points thanks to a robust system of development banks, including KfW Bank. In South Korea, access to financing is at 70–75 points and is supported by active government assistance through the Korea SMEs and Startups Agency.

In Uzbekistan, the index of access to financing remains at 40–50 points, indicating the existence of significant constraints, particularly in rural and remote regions. The underdevelopment of regional financial institutions and limited access to credit resources significantly hinder the development of small businesses and reduce the effectiveness of existing economic mechanisms.

An analysis of regional differentiation shows that in the United States and Germany, it remains low thanks to effective regional policies and developed infrastructure. South Korea exhibits a moderate level of differentiation, driven by the concentration of economic activity in technologically advanced regions.

In Uzbekistan, by contrast, high regional differentiation is observed, manifested in significant disparities between economically developed centers and peripheral areas.

Thus, the results of the analysis indicate that in Uzbekistan, small businesses play a key role in ensuring employment and generating GDP; however, their development at the regional level is constrained by limited access to financing, underdeveloped infrastructure, and high territorial differentiation. Unlike in developed countries, where economic mechanisms are systemic and decentralized, in Uzbekistan there remains a need for their further adaptation to regional conditions in order to improve the efficiency of small business operations.

Policy Recommendations

Based on the findings, the following measures are recommended for improving regional small business development in Uzbekistan:

1. Expand Decentralized Governance

Grant broader authority to regional administrations to design entrepreneurship support measures based on local specialization and needs.

2. Develop Regional Financial Institutions

Create regional guarantee funds, microfinance systems, and blended-finance mechanisms for SMEs.

3. Strengthen Infrastructure

Expand industrial zones, logistics centers, digital platforms, incubators, and technology parks in lagging regions.

4. Promote Innovation and Export Orientation

Support start-ups, e-commerce exporters, and technology-based firms through targeted grants and training.

5. Reduce Regional Disparities

Introduce differentiated support packages for less-developed territories, especially rural areas.

Conclusion

The study confirms that small business development at the regional level is a critical determinant of sustainable economic growth, employment expansion, and balanced territorial progress. Comparative analysis shows that countries with decentralized institutions, diversified financing systems, and developed entrepreneurial infrastructure achieve stronger SME performance.

In Uzbekistan, small business already performs an important socio-economic role, particularly in employment creation. Nevertheless, its regional potential is constrained by centralized policy mechanisms, insufficient access to finance, infrastructure gaps, and territorial disparities.

Therefore, the modernization of economic mechanisms should focus on adaptive regional governance, stronger local financial ecosystems, innovation support, and infrastructure expansion. Implementation of these measures would improve the competitiveness, productivity, and resilience of small business entities across the regions of Uzbekistan.

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MECHANISMS AND PATHWAYS OF STRATEGIC COUPLING BETWEEN CHINA AND UZBEKISTAN UNDER THE RESTRUCTURING OF GLOBAL VALUE CHAINS

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https://doi.org/10.5281/zenodo.20033896

Abstract. *The essence of contemporary Global Value Chains (GVCs) is not solely encapsulated in theoretical constructs but is vividly manifested in practical settings such as the Jizzakh BYD plant and the Pengsheng Industrial Park's copper production lines. This study eschews conventional academic discourse in favor of exploring the pragmatic mechanisms underpinning the industrial relationship between China and Uzbekistan. The analysis reveals a significant transformation in trade dynamics, transitioning from traditional "resources-for-market" exchanges to a dual-coupling mechanism that combines relational and modular governance, facilitating Uzbekistan's ascent in the industrial hierarchy. Crucially, this partnership addresses the challenges of being "doubly landlocked." By employing a framework that emphasizes "rules for space," both nations have effectively converted geographic limitations into a competitive advantage in the region. The implementation of substantial infrastructure projects, such as the CKU Railway, complemented by innovative financial strategies, epitomizes the shift towards regional resilience. Ultimately, this examination underscores how regional synergies can effectively redefine a nation's global positioning.*

Keywords: *global Value Chains (GVCs); Strategic Coupling; Institutional Embeddedness; Industrial Upgrading; Regional Value Chains (RVCs).*

1. Introduction

The contemporary international division of labor faces profound challenges characterized by fragmentation in production alongside increasingly intricate regulatory frameworks. The traditional notion that geographic limitations represent an immutable constraint is being revisited. Current regional economic dynamics demonstrate that through concerted institutional efforts and strategic policy interventions, a region can reconstitute its role within the global network. This evolution is particularly pronounced in the context of rising trade tensions and health crises, which have prompted a shift towards tighter Regional Value Chains (RVCs). The focus on resilience represents a strategic pivot towards "near-shoring," affording China a critical opportunity to strengthen its connections with "Belt and Road" partners.

Uzbekistan exemplifies this transformation. Historically viewed as a marginal supplier of raw materials within the constraints of being a "doubly landlocked" nation, the country has undergone significant changes since the implementation of the "Uzbekistan 2030 Strategy" in 2016. By actively pursuing a robust digital and industrial upgrade, Uzbekistan is reshaping its economic landscape. Concurrently, China is evolving from being a mere conduit for external markets to establishing its own "Dual Circulation" economic system. This bilateral relationship

transcends traditional trade paradigms, intertwining both nations' industrial trajectories. The exploration of how these states navigate geographic constraints through strategic coupling is not only a pertinent academic inquiry but also a crucial survival strategy for regional economic development.

2. Literature Review

The theoretical foundation of global cooperation has long been anchored in Global Value Chain (GVC) analysis, although the framework has undergone substantial evolution. Initially focused on the mechanisms by which developing countries could upgrade products, the perspective has shifted towards the nuanced understanding of value extraction facilitated by modern accounting practices. However, this traditional logic is increasingly inadequate in the face of contemporary geopolitical realities and the iterative dismantling of globalization, necessitating a new survival strategy predicated on resilience through Regional Value Chains (RVCs). This methodological shift provides a pragmatic lens through which to assess the operational effectiveness of the “Belt and Road Initiative” in promoting regional integration.

China's economic engagement with Central Asia represents a critical juncture, as the relationship transitions from basic exchanges of raw materials to a more sophisticated blending of industrial expertise. Through significant investments and substantial infrastructural undertakings, particularly the development of the CKU Railway, China is facilitating the establishment of a comprehensive regional technology and energy network. For Uzbekistan, this relationship catalyzes a structural transformation, linking the targets of the “Uzbekistan 2030” initiative with Chinese technological capital. This partnership enables Tashkent to evolve from a passive supplier to an active regional hub, leveraging advancements in green and digital sectors to escape the confines of resource dependency and geographic isolation.

Geographic limitations, previously considered immutable for a “doubly landlocked” country, are being redefined through a strategic synthesis of “hard” infrastructure projects and “soft” institutional enhancements. The establishment of rail connections and the integration of regulatory standards represent an innovative approach to mitigating the disadvantages of geographic isolation. The current research systematically deconstructs this dynamic, analyzing the governance frameworks, the measurable ascent of Uzbekistan within the value chain, and the impact of new spatial initiatives on operational costs. The objective is to illustrate a transformative paradigm that extends beyond rail connectivity to foster significant regional development.

3. Methods

This research employs a qualitative multi-case study design, utilizing theoretical sampling to identify meaningful instances of China-Uzbekistan cooperation. The aim is to encapsulate a diverse spectrum of industry types and coupling mechanisms that elucidate the complexities of the bilateral relationship.

The analysis of resource-driven sectors primarily focuses on the copper and sanitary ware clusters located within the Pengsheng Industrial Park. This case serves as a pertinent illustration of how host countries can leverage their raw materials to ascend the value chain, exemplifying relational governance in practice.

In high-technology sectors, the investigation centers on the BYD-UzAuto Motors joint venture situated in Jizzakh. This project in the New Energy Vehicle (NEV) sector not only underscores the transition from traditional automotive production to advanced technology transfer but also serves as a prime example of modular governance, wherein standardized technological components are integrated into existing local production frameworks.

Complementary to these primary cases, the analysis incorporates the SCO Agricultural Technology Demonstration Park and the CKU Railway project. These cases facilitate an exploration of technological dissemination in agriculture and the transformative potential of major infrastructure initiatives in reshaping cross-border institutional frameworks.

Data for this study was meticulously collected through the analysis of official corporate records, trade communications, and policy documents from both China and Uzbekistan. Additionally, media coverage was leveraged to fill informational gaps and ensure the robustness of the analysis. A thorough cross-examination of multiple data sources was conducted to validate the authenticity and reliability of the findings.

4. Research Results

4.1 Value Chain Coupling: Relational vs. Modular Logic

The empirical data indicates that the industrial synergy between China and Uzbekistan does not conform to a singular model of interaction. Rather, a “dual-drive” approach emerges, characterized by an amalgamation of relational and modular frameworks that adapt according to the specific industrial context. This fluidity serves as the bedrock for effective strategic coupling.

In the context of the Pengsheng Industrial Park, particularly within the copper and sanitary ware clusters, relational governance emerges as the predominant mechanism. The complexity inherent in producing high-quality faucets, which necessitates numerous intricate processes such as precision casting and electroplating, requires a collaborative effort that transcends mere transactional relationships. Rather than simply exporting machinery, Chinese firms engaged in a comprehensive process of localized adaptation. This extended period of collaboration involved meticulous adjustments to production lines, aligning them with the specific attributes of Uzbek raw materials. This nuanced transfer of knowledge and practice exemplifies a robust framework of relational governance, allowing Uzbekistan to transition from exporting raw minerals to producing high-value manufactured goods.

In contrast, the NEV sector illustrates the efficacy of a modular approach. The BYD-UzAuto Motors venture symbolically represents modular governance, whereby BYD, as the technological leader, provides standard modular components. The Uzbek partner utilizes its existing manufacturing base to integrate local parts into the production process while managing sales operations. By adhering to established modular designs, Uzbekistan was able to streamline its entry into high-tech manufacturing, thus facilitating a rapid development of a local supply chain.

4.2 Multidimensional Pathways to Industrial Upgrading

The analysis extends beyond mere trade metrics, highlighting Uzbekistan’s progression along the industrial continuum—from basic processing improvements to capturing control over significant segments of the value chain.

In the agricultural domain, the SCO Agricultural Technology Demonstration Park has revolutionized operational practices through the implementation of smart irrigation systems and data-driven platforms. This transition represents a paradigm shift from traditional farming techniques to more precision-oriented methodologies, enabling local producers to elevate the quality of their goods and align them with international retail standards.

Moreover, the transformation on the ground is underscored by the transition of labor roles; workers formerly engaged in manual tasks are now increasingly involved in management positions, utilizing methodologies such as Lean Production and Total Quality Management—a clear indication of upward mobility in the Global Value Chain. The integration of these parks into

the local economic fabric, coupled with social initiatives to link commercial success to community development, fosters informal trust and ensures long-term sustainability, demonstrating the concept of "social upgrading."

4.3 Hedging Geographical Constraints through Institutional Innovation

Uzbekistan's status as a "doubly landlocked" nation presents structural challenges. To address these issues, the partnership with China has adopted innovative measures, prioritizing the integration of rules and standards to circumvent traditional diplomatic limitations.

While the CKU Railway constitutes a significant infrastructural investment, it serves as more than merely a transportation route; it symbolizes an "institutional corridor." The operational effectiveness of this corridor is enhanced by the integration of technological systems such as Electronic Data Interchange (EDI) and standardized customs documentation across multiple jurisdictions. This composite solution—merging physical infrastructure with regulatory harmonization—aims to reduce transit times substantially, thereby transforming a geographic disadvantage into a strategic advantage.

In tandem, advancements in digital infrastructure facilitated by partnerships with companies such as Huawei have established a robust framework of fiber optics and 5G connectivity. This technological backbone not only enhances internet connectivity but also enables seamless integration of Manufacturing Execution Systems (MES) and research and development functions across borders, effectively mitigating conventional managerial delays associated with geographical distances.

The 1 GW photovoltaic project further exemplifies the collaborative financing model. A project of this scale necessitated a blend of funding from Chinese institutions and financial risk mitigation through entities such as Sinosure. This comprehensive approach, which combines technology, capital, and credit, is instrumental in enabling Uzbekistan's transition away from fossil fuel dependency while simultaneously managing financial risk.

5. Discussion

The results of this study prompt a reconsideration of assumptions prevalent within Global Value Chain (GVC) theory and regional development paradigms.

The analysis indicates that "strategic coupling" is not a monolithic process. The illustrative case of China and Uzbekistan elucidates that the effectiveness of a partnership's governance structure—whether relational or modular—depends on a deliberate alignment of industrial capabilities, transaction complexity, and the practical capabilities of the host country. Shifting from a rigid conceptualization of coupling facilitates an understanding of how "latecomer" economies can forge enduring partnerships that withstand changing circumstances.

Additionally, the traditional characterization of "geographical constraints" merits reevaluation. The notion that being landlocked represents an insurmountable barrier is being challenged by examples such as the CKU Railway's "rule-based connectivity," as well as the integration of digital infrastructure and innovative financing solutions. These components function as tools for redefining locational advantages, contesting the deterministic notion that "geography is destiny." This perspective positions development as a process more informed by the specific strategies employed to alleviate transaction-related frictions than by initial geographic conditions.

The policy implications for the "Belt and Road" initiative suggest that successful outcomes depend on more than infrastructural investments; there is a critical need to synchronize governance frameworks and harmonize industry standards. By proactively engaging in digital and green

sectors, Uzbekistan has the potential to evade both the “resource curse” and the pitfalls of low-value production, positioning itself for a significant economic leap forward.

While this research adopts an exploratory approach, utilizing qualitative case studies to illuminate the underlying characteristics of strategic coupling, it offers insights that warrant further quantitative examination. Future studies could employ extensive surveys to quantify factors such as technological spillovers and the distribution of value-added gains across various governance models.

6. Conclusion

In a reconfigured landscape of Global Value Chains focused on resilience, the partnership between China and Uzbekistan transcends traditional trade dynamics, embodying a sophisticated paradigm of Regional Value Chain co-construction.

This partnership succeeds precisely because it is not governed by a rigid template; the integration of relational and modular governance facilitates a comprehensive alignment of disparate economic activities, ranging from raw material processing to advanced manufacturing in the NEV sector. Beyond mere output figures, this collaboration has induced a transformative shift within Uzbekistan’s economy, unlocking processes and functional upgrades once deemed unattainable.

A central insight from this analysis lies in how this partnership strategically navigates geographic limitations. By integrating “soft” institutional frameworks with “hard” infrastructural investments—streamlining digital networks and transport standards—both nations have successfully mitigated the costs associated with being landlocked. As a result, Uzbekistan is evolving from a hinterland into a strategic nexus for trade across Eurasia.

Looking forward, it is imperative to consolidate these advancements by emphasizing the importance of “soft connectivity,” such as standardized data systems, alongside enhanced training in human capital. Fostering innovative digital tools for resilient production networks will not only benefit the bilateral collaboration between China and Uzbekistan but also establish a framework that other landlocked nations can adopt to address their own structural challenges.

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HOW BUSINESSES DEPLOY DIGITAL PLATFORMS IN UZBEKISTAN: DYNAMICS OF GROWTH

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https://doi.org/10.5281/zenodo.20033935

Abstract. *In this article, the author examines internal conditions and legal, economic, technological, and personnel resource provision trends in the development of management and decision-making systems at enterprises in Uzbekistan. Analyzing the outcomes of two-year survey results, the author revealed trends, achievements and challenges of businesses facing developing digitalization and digital transformation of their business operations. The research outcomes may help to understand the practical experience and ICT strategies of businesses and fine-turn digital transformation strategies and related actions implemented by public administration bodies in Uzbekistan. The case can be useful for other developing countries to foster national digital strategies.*

Keywords*: digitalization, digital transformation, use of ICT in businesses, survey on digitalization.*

Introduction

Digital readiness of enterprises should be understood as the comprehensive ability of an organization to implement modern information and communication technologies to improve processes, create new value, and enhance management and decision-making efficiency to enhance competitiveness. It encompasses infrastructure, personnel skills, organizational culture, and transformation strategy.

Digital readiness of an enterprise, including technological infrastructure and personnel competencies, directly improves the effectiveness of management decisions through process automation, access to operational data, digital transformation of decision-making, and risk mitigation. The implementation of technologies (Big Data, Artificial Intelligence) accelerates decision-making, reduces costs, and increases business agility, which is critical for competitiveness.

Rapidly evolving technologies and the rapid changes ubiquitous in today's world pose significant challenges for organizations, while simultaneously offering innovative opportunities for those able to capitalize on them in this era of globalization, technological advancement, and productive capacity. There is no doubt that deepening digitalization and digital transformation, as well as the application of artificial intelligence in management and decision-making, will have significant positive, and possibly negative, impacts on societies in low- and middle-income countries (Annarelli et al., 2021, Fadhlurrahman, 2024). Digital management and decision-making platforms, fueled by increasing computing power, expanded connectivity, and big data, offer exciting opportunities to support economic growth and effectively address a wide range of management and decision-making challenges at the enterprise, industry, and national economic levels. The ensuing changes will be significant and potentially transformative in the roles of humans and technology in decision-making and the production of goods and services.

The growth and development of digitalization, digital transformation, and AI are leading to an increasing impact on future economic and social change (Kraus et al., 2021, Mahraz et al.,

2019, Reis et al., 2018, Vial, 2019, Wang et al, 2021). According to the European Union Digital Transformation Monitor (EMIS, 2017), the economic impact of digital solutions and artificial intelligence could reach €13.3 trillion by 2030. Research shows that the implementation and development of artificial intelligence can lead to an increase in labor productivity of up to 40% and significant growth in retail, education, electricity, manufacturing, healthcare, and other sectors. The development of digital platforms and AI can be realized not only in the governmental but also in the organizational aspects, bringing benefits such as personnel management through cost reduction (Farias-Gaytan et al, 2023, Egodawele et al., 2022), customer attraction and strengthening of market positions, cost savings, and more (Pan et al., 2021, Gomes et al., 2020, Andriushchenko et al, 2020).

This section examines trends in the development of technological, organizational, administrative, and strategic aspects of the implementation and expansion of digital systems in enterprises across the country. To this end, a study was conducted through a survey of business entities to gain a deeper understanding of the state of digitalization and digital transformation of economic processes at various enterprises in Uzbekistan. The study primarily focused on enterprises that have implemented digitalization and use relevant information systems in economic management. The survey, conducted over several years, demonstrates the dynamics of enterprise digitalization.

Methodology

The research methodology was based on a survey of focused group of companies that had more advanced practical experience in ICT applications in business operations. The survey was conducted during consecutive two years to compare certain trends in maturity of ICT applications in local businesses. The survey questionnaire consisted of 18 questions. In the first year of the survey research involved 42 companies and in the second year 26 companies responded the survey questionnaire. These companies operated in various sectors of economy such as education, ICT, tourism & hospitality, financial institutions & banking, chemicals, oil & gas, public administration, agriculture, legal services, trade and entrepreneurship. The survey responses were quantified to represent response categories as specific numbers. These numerical values were analyzed using basic exploratory data analysis method, namely using frequency distribution analysis in each year, and the outcomes of the analysis were visualized and presented in bar-diagrams and radar-diagrams considering complexity of responses. A deductive method was used to discuss visualized research outcomes. The research finding was summarized with specific conclusion.

Findings

Considering the need for various types of information systems implemented by organizations in the country, it is clear that customer relationship management (CRM) is the most widely adopted, with half of respondents effectively using it. During the survey period, growth in the use of each type of information system was observed, particularly for enterprise resource planning (ERP) systems, which grew by approximately 31%. Furthermore, management information systems (MIS) have gained popularity among companies, demonstrating rapid growth: from 19% of respondents to over 42%, putting them on par with customer relationship management (CRM) systems. Interest in knowledge management systems (KMI) has increased, but compared to other types of information systems, it has shown the smallest growth (Figure 1). The most important aspect of the development of digitalization in the economy is the digital transformation of business processes. The next criterion for the survey was which business processes are currently implemented using information systems. Based on the participants'

responses, three most popular areas of activity were identified: finance and accounting, quality control, and sales and marketing. It is noteworthy that the implementation of digital quality control systems has shown growth, outpacing information search, logistics, human resources management, and research and development, which also showed a certain increase in adoption. Significant growth has also been observed in the implementation of digital warehouse management systems (Figure 2).

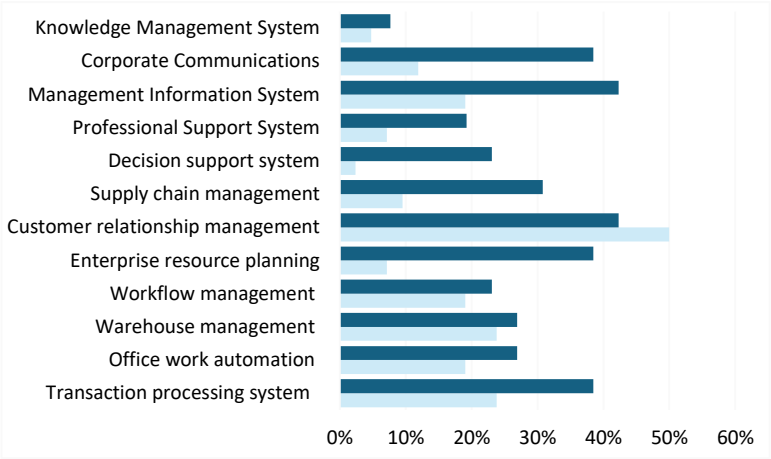


Figure 5. Information systems used in enterprises in Uzbekistan.

One of the most important research questions was to determine the tangible and intangible benefits of implementing digital systems (Figure 3). The results of the study showed that the implementation of digital systems has contributed to increased efficiency, resulting in reduced production and management costs, as well as increased customer satisfaction.

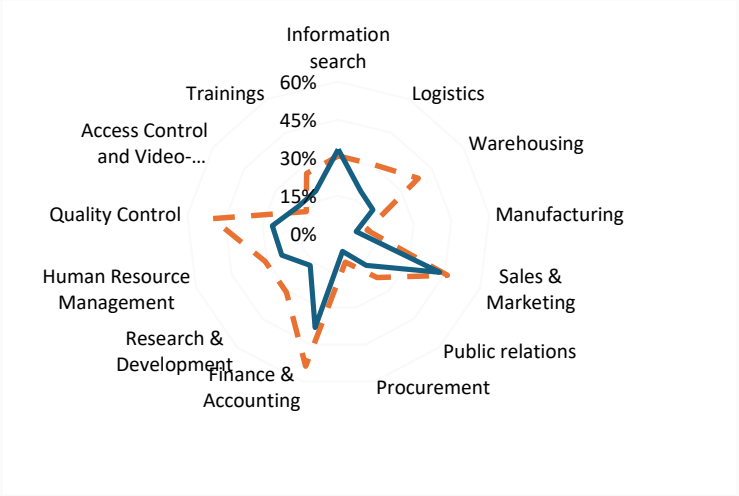


Figure 6. Dynamics of digitalization of business processes in enterprises in Uzbekistan.

Digitalization also contributed to increasing the value of information in management activities and, especially, improving the quality of decisions. Furthermore, the companies surveyed noted that digitalization led to increased revenue and return on investment.

A study of the scale of digitalization implementation in enterprises revealed positive trends in the expansion of digitalization (Figure 4). A very important trend is noted: a transition from digital solutions at the scale of individual departments to integrated corporate digital solutions. A significant increase in the use of digital systems at national, international, and global scales by enterprises in the country is also noted. Overall, the use of digital systems in Uzbekistan is expanding at a significant pace.

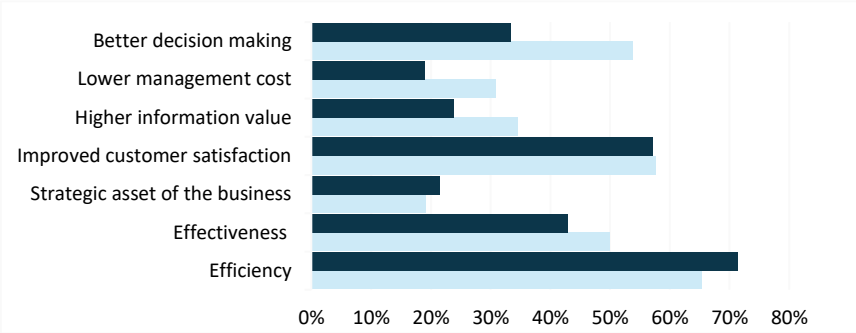


Figure 7. Dynamics of change in benefits from digitalisation.

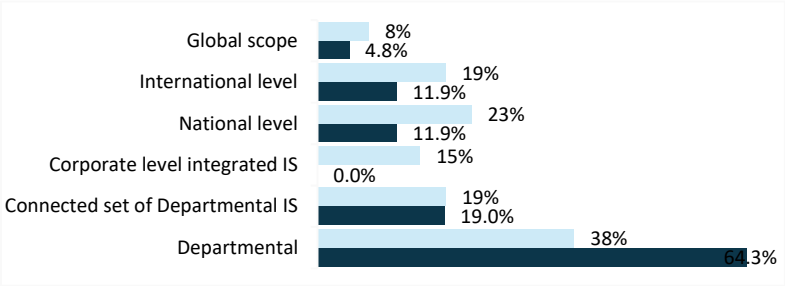


Figure 8. Scope of digitalization in enterprises.

A crucial factor in the development of digitalization and digital transformation of the economy is the availability and use of information and communication technology resources. Analysis of the study results revealed that enterprises in our country utilize computing systems and centralized data storage platforms at various levels (Figure 5). The most important indicator of the development dynamics in this context is the significant growth in the adoption of centralized computing and data storage systems (data centers), the expansion of corporate digital systems, and the expanding use of cloud systems in the practice of digitalization and digital transformation of enterprises. This trend in the development of technologies for creating enterprise digitalization platforms is a positive indicator of improved quality, technological understanding, and the effectiveness of digital solutions, and is a particularly important prerequisite and technological foundation for the implementation of more complex digital decision-making systems based on predictive and prescriptive analytics.

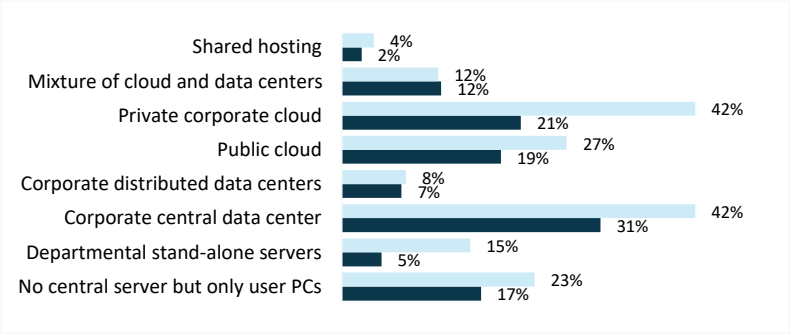


Figure 9. Computing technology used in enterprises.

The implementation of effective digital transformation of decision-making systems requires the availability of centralized platforms for structured and reliable storage of big data on enterprise economic activity. The study revealed a significant increase in the adoption of structured databases and a rapid increase in the use of cloud storage by enterprises across the country. It is noted that data backup for the reliability and resilience of digital systems has become more widely used, with a particular increase in the use of cloud systems instead of external data backups. This trend demonstrates the growing value of digital information in enterprise operations. It should be

noted that the respondent enterprises lack backup data centers for use in emergency situations. Such solutions require colossal investments and ongoing costs, which pose an unbearable financial and technological burden for local enterprises. Nevertheless, enterprises have begun to increasingly utilize cloud technologies from external ICT service providers instead of expensive in-house data centers with backup computing and storage resources. It should be noted that the "Law of the Republic of Uzbekistan on Personal Data" will create an incentive for the implementation of in-house data centers or the use of cloud-based data processing and storage solutions within the country [ ]. Data security is one of the most important aspects of the effective operation of digital systems for every enterprise. More than half of the companies surveyed indicated that the primary measures for ensuring information security include corporate information policies, employment contracts, and regular network security management. This study notes an increase in the attention and efforts of enterprises to ensure the cybersecurity of digital systems, but the scale of digital security system implementation remains insufficient.

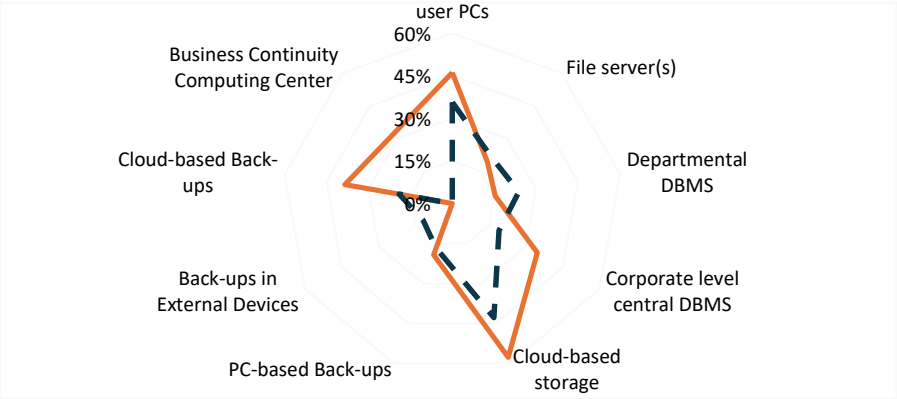


Figure 10. Data storage technologies applied in businesses.

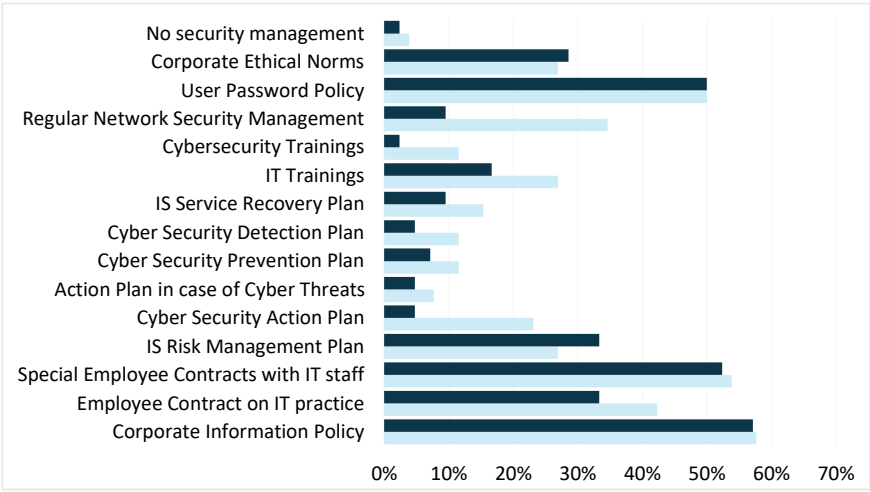


Figure 11. Dynamics of application cybersecurity systems.

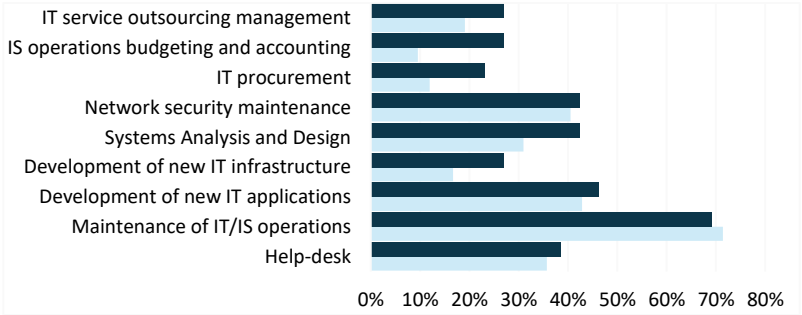


Figure 12. Dynamics of growth of ICT service functions in enterprises.

When considering organizational and administrative issues related to digitalization and digital transformation, it's particularly important to note the importance of organizing activities for the development, management, and support of tasks to ensure the sustainable operation of digital platforms—the continuous operation of technologies, the existence of appropriate job functions, rules and policies, and a management hierarchy. When examining the main functions of the organization's IT department, all indicators demonstrated growth during the survey period (Figure 7). While functions such as the development of new IT applications, systems analysis and design, and network security maintenance showed modest growth, the level of outsourcing, procurement, budget management, and ICT service accounting increased, indicating increased investment and its integration into the development of ICT platforms.

The increasing number of companies outsourcing business process reengineering services should also be considered. This growth in outsourcing also demonstrates that the ICT services market is growing and the range and complexity of services is expanding.

A study of the dynamics of changes in the range of outsourced services shows that the expanding use of ICT systems in enterprises has increased the level of hosting (location) of digital platforms in external specialized data centers and strengthened the vertical integration of digital systems technical support functions within the enterprise structure (Figure 9).

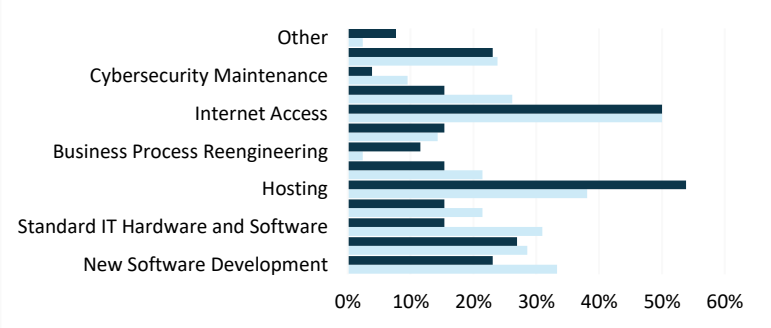


Figure 13. Outsourcing of ICT services in enterprises.

The creation, support, and development of digital management and decision-making systems requires significant financial investment. Creating a digital system is not a one-time investment project; rather, it requires ongoing funding for its maintenance and development. These expenses must be appropriately reflected in the budget plan. The management and funding of digital systems determines the quality of the system itself and the direction of its strategic development.

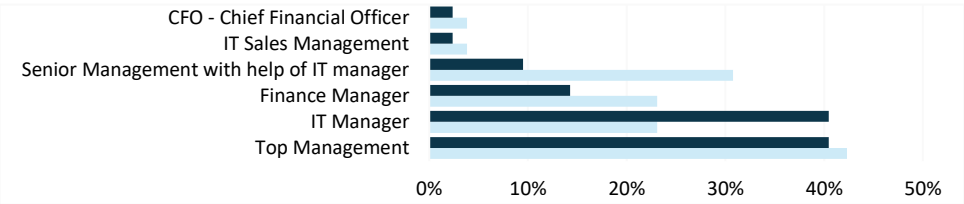


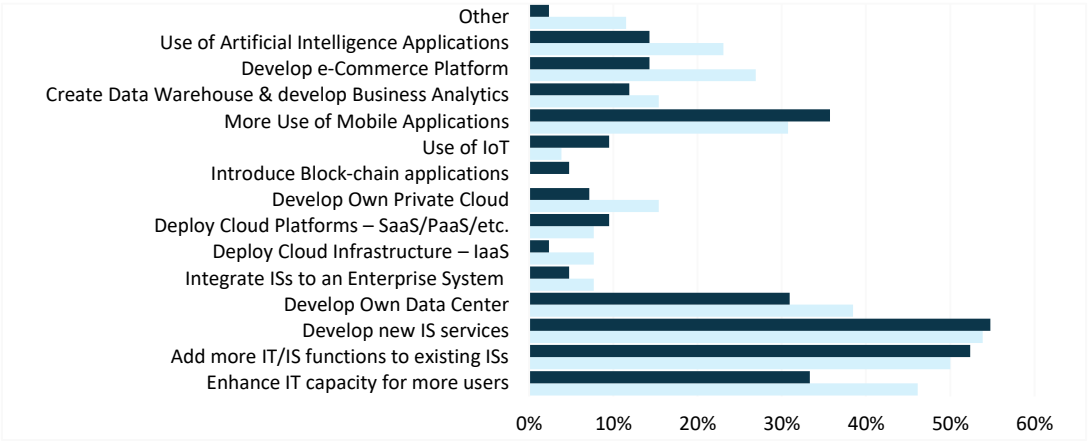
Figure 14. Change dynamics in IT management.

The study showed that responsibility for the development and funding of digital systems is increasingly being assigned to senior management (Figure 10). This trend is quite positive, as senior management recognizes the strategic importance of digital management and decision-making systems and, therefore, takes personal responsibility for their development.

This study examined an equally important factor playing a decisive role in the development of digital management and decision-making systems: enterprises' strategic plans for the future development of information systems. Positive dynamics are noted in the strategic focus of digital

platform development toward the implementation of more complex management and decision-making information systems. Enterprises increasingly plan to expand their client base and increase the computing potential of centralized data centers, deepen their digital transformation by developing business analytics and e-commerce platforms, and create conditions for the effective use of artificial intelligence solutions in decision-making (Figure 11). This fact is also confirmed by the fact that fewer enterprises plan to invest in existing digital systems and expand digital services. It is precisely the strategic investment plans of enterprises in the development of high-tech digital systems that create favorable conditions for the expanded use of more effective digital decision-making systems and artificial intelligence-based solutions.

Figure 15. Digital systems development strategies of enterprises.



Conclusion

The above study aimed to examine the internal aspects of enterprises regarding their economic, technological, and administrative-organizational measures for the development of digital management and decision-making platforms. Summarizing the findings of this study, the following key points should be noted:

- the use of digital platforms is expanding, with the primary benefit being reduced production costs;
- the use of digital systems to create additional value is in its infancy;
- there is a positive trend toward centralization and strengthening of technology platforms, as well as the increasing adoption of cloud-based digital solutions;
- there is a growing understanding of the value of data and information, and efforts aimed at ensuring cybersecurity are strengthening;
- enterprise digital strategy plans are focused on the creation of e-commerce platforms, data analytics, and the application of artificial intelligence.

The above trend demonstrates that enterprises are beginning to invest in deepening the digitalization of business processes and supporting the digital transformation of their business platforms to create additional economic value and ensure effective decision-making.

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IMPLEMENTING BLOCKCHAIN IN ACCOUNTING: THE ROLE OF THE TOE FRAMEWORK

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Abstract*. This study examines blockchain adoption in accounting through the Technology–Organization–Environment (TOE) framework, with particular attention to the role of trust as a key driver of implementation. The research argues that blockchain can improve accounting systems by enhancing transparency, data reliability, transaction security, process automation, and compliance with regulatory requirements. However, its practical adoption remains limited due to technological uncertainty, organizational readiness, and external institutional pressures. Using a multi-method approach, the study reviews existing literature, identifies relevant TOE factors, and analyzes previous empirical findings on blockchain implementation in accounting and auditing. The findings show that trust in blockchain does not influence adoption in isolation; rather, its effect is mediated by technological advantages, managerial support, technological readiness, and environmental conditions. The study contributes to the literature by conceptualizing trust-based blockchain adoption in accounting and offering practical recommendations for organizations seeking to modernize accounting systems through digital innovation.*

Keywords: *blockchain, accounting, process automation, TOE framework, trust, technology adoption, digital transformation.*

INTORDUCTION

The use of digital accounting systems based on information technologies contributes to greater operational efficiency and the generation of analytically meaningful information. However, the level of automation remains limited due to the complexity of complying with mandatory regulatory requirements, which hinders the full digital transformation of accounting procedures. As a result, a significant portion of accounting operations is still performed manually, maintaining a high level of labor intensity and reducing the potential for optimization.

Under these conditions, distributed ledger technology, known as blockchain, is of particular interest, as it possesses fundamentally different characteristics compared with traditional information systems. This technology operates as a decentralized, open, and cryptographically secured data storage system that does not require a trusted intermediary, thereby creating the conditions for improving the transparency and reliability of accounting information.

The application of blockchain in accounting offers opportunities to automate processes at the basic level while simultaneously ensuring compliance with regulatory requirements. The technology has the potential to transform key stages of the accounting cycle, including the recording of business transactions, the preparation of financial reports, and the analytical processing of data. In addition, it creates conditions for modernizing the traditional double-entry

accounting system through the introduction of more advanced forms of transaction recording and verification.

At present, the development and practical implementation of information solutions based on blockchain technology in the field of accounting remain limited. A significant factor restraining this process is the insufficient development of scientific approaches to analyzing the dynamics of the adoption of such technologies, which slows the formation and dissemination of relevant applied solutions.

Considering the significant transformative potential of blockchain for the accounting profession, there is a growing need for a comprehensive study of the processes of its adaptation and practical use in accounting activities. This study pays particular attention to analyzing the contextual factors that influence the implementation of distributed ledger technology in accounting, which has both theoretical significance and practical value for the professional field.

One of the key conditions for the successful implementation of any innovative technology is the level of trust among users. The academic literature has repeatedly confirmed that trust in information systems has a significant influence on their acceptance and diffusion across various fields, including public administration and digital services [1].

For accounting practice, the reliability of information and resistance to fraudulent activities remain critically important characteristics. In the traditional model of financial relations, trust is ensured through centralized institutions, such as banking organizations and government bodies, which perform the functions of data verification and confirmation.

In contrast to this approach, blockchain technology implements the principle of decentralization by forming a distributed system for storing and verifying data without the involvement of a single controlling authority. The transaction ledger is maintained by multiple independent network nodes, which fundamentally distinguishes this technology from conventional information systems. At the same time, trust is not eliminated as a category; rather, it is transformed: it shifts from institutional intermediaries directly to the technological infrastructure.

The automation of accounting procedures, while simultaneously ensuring compliance with regulatory requirements, increases the importance of trust in blockchain-based solutions among accounting professionals. They need to evaluate not only the functional capabilities of the technology but also its ability to ensure data protection, operational transparency, and fraud prevention.

Thus, trust acts as one of the determining factors in the implementation of blockchain in accounting practice. At the same time, the academic literature still lacks sufficient elaboration of the mechanisms through which trust influences decision-making on the implementation of this technology at the organizational level [2].

In this regard, the following research question is formulated:

Is there a relationship between the level of trust that accounting professionals have in blockchain technology and the decision to implement it?

It should be noted that the implementation of blockchain-based accounting systems represents a managerial decision at the organizational level, requiring a comprehensive analysis from the perspective of the theory of the firm. However, most existing studies focus primarily on the technological characteristics of blockchain and the assessment of its functional applicability, while the organizational and institutional aspects of implementation remain insufficiently explored.

Based on the theoretical premises outlined above, this study applies the conceptual Technology–Organization–Environment (TOE) framework, which assumes that organizational characteristics can perform a mediating function in the relationship between trust in blockchain technology and its implementation in accounting activities.

According to this logic, the formation of trust in blockchain-based solutions strengthens the influence of technological, organizational, and environmental factors within a company, which, in turn, increases the likelihood of a managerial decision to implement the relevant systems [3].

Do the factors of the TOE framework act as mediators in the relationship between accounting professionals' trust in blockchain technology and the decision to implement it?

The rapid development of distributed ledger technology, combined with its insufficient theoretical elaboration, highlights the strong relevance of the issue under consideration and forms a promising direction for further scholarly research.

At the first stage of the study, a theoretical model was developed, after which it was empirically tested with a focus on analyzing the role of trust in the implementation of blockchain-based solutions in accounting practice. Particular attention was paid to examining the mediating effect of TOE factors in the context of the digital transformation of accounting systems.

The methodological basis of the study relies on a multi-method approach aimed at taking into account the specific features of the research context. Accordingly, a sequential three-stage research design was implemented.

At the first stage, a systematic analysis of the academic literature was carried out, making it possible to summarize existing theoretical approaches and identify key research directions.

At the second stage, qualitative coding procedures were applied to identify the factors influencing the implementation of blockchain technologies in the accounting field.

LITERATURE REVIEW

The results, together with the findings presented in the academic literature, served as the basis for identifying relevant contextual variables within the TOE framework, as well as for constructing the research model and formulating the corresponding hypotheses.

At the third stage, the analysis was based on questionnaire data previously collected by other researchers. Statistical processing of these data made it possible to assess the extent to which the proposed hypotheses were supported.

The structure of the study is logically organized in accordance with the stages outlined above: from theoretical justification to empirical analysis, followed by a discussion of the results and the formulation of theoretical and practice-oriented conclusions [4].

Contribution of the Study

The present study makes a significant contribution to the development of scholarly understanding of the implementation of innovative technologies in accounting.

First contribution.

The study proposes a model for implementing blockchain-based solutions in accounting systems, with trust as its central factor. To provide empirical justification for this model, the results of questionnaires and other empirical studies previously conducted by other authors were examined. This approach expands existing research on the diffusion of innovations by emphasizing the specific features of the perception and adoption of distributed ledger technology in the professional environment of accountants.

Second contribution.

The study analyzes research findings related to the mediating role of the Technology–Organization–Environment (TOE) framework in the implementation of blockchain-based solutions. This framework is widely used in studies of innovation diffusion at the organizational level and serves as a comprehensive methodological basis for analyzing the factors that influence the implementation of technological innovations. Although the influence of TOE components on innovative decision-making has been repeatedly discussed in the literature, their mediating function in the relationship between trust in technology and its implementation in accounting practice has been studied only to a limited extent. The present study addresses this gap by drawing on existing empirical data.

Third contribution

Building on the proposed approach, the study conceptualizes the mediating role of the identified factors and emphasizes the need to comprehensively consider technological, organizational, and environmental conditions. The analysis of existing empirical studies shows that assessing the advantages and limitations of blockchain technology within these dimensions helps build user trust and increases the likelihood of successful implementation.

In addition, the study identifies the key determinants of blockchain adoption in accounting and formulates practice-oriented recommendations that are of interest both to the academic community and to specialists involved in the digital transformation of accounting systems [5].

At the initial stage of the study, a systematic analysis of the current state of research on the adoption of information technologies was conducted. This made it possible to identify stable research directions, characteristic trends in the development of innovative solutions, as well as existing theoretical and empirical gaps.

Technology Adoption in Information Systems

The issue of technology adoption occupies a central place in information systems research. In the academic tradition, various theoretical models are widely used to explain the mechanisms through which specialists, including those in the field of accounting, accept and use new technologies.

The most common models include:

– the Technology Acceptance Model (TAM);

– the Theory of Planned Behavior (TPB);

– the Unified Theory of Acceptance and Use of Technology (UTAUT) [6].

These concepts are actively used to analyze the adoption of digital solutions in accounting practice. In particular, they have been applied in studies of areas such as electronic auditing, digital tax filing, the use of electronic invoices, and automated accounting systems.

Nevertheless, despite the considerable number of studies in this field, the application of these models to the study of blockchain technology adoption remains limited, which further confirms the relevance and scientific novelty of the present study.

RESULTS AND DISCUSSION

Contemporary academic literature offers a wide range of theoretical approaches for analyzing the factors that influence technology adoption at both the individual-user level and the organizational level. At the same time, information systems research traditionally differentiates the levels of analysis into three interrelated categories: the micro level, referring to the individual user; the meso level, referring to the organization; and the macro level, referring to the external environment and the innovation market. Given that the subject of the present study is the implementation of blockchain technology in accounting applications, the meso-level approach,

focused on decision-making processes within organizations, was selected as the main analytical perspective. This choice is explained by the fact that the implementation of accounting systems represents a strategic managerial decision made at the company level and requires consideration of a combination of internal and external factors.

From an organizational perspective, the process of technology adoption is determined not only by the characteristics of the innovation itself but also by managerial, organizational, technological, institutional, and individual conditions. Interorganizational interactions and parameters of the external environment, which shape the context of decision-making, are also of considerable importance. A comprehensive analysis of information system adoption at the enterprise level requires consideration of several key aspects, including managerial and organizational characteristics, the level of technological readiness, the influence of the external environment, and the behavioral characteristics of the participants in the process. In this regard, conceptual approaches such as the Diffusion of Innovations theory (DOI) and the Technology–Organization–Environment (TOE) framework have become widely used in academic practice and have proven effective in studying the adoption of digital solutions. The TOE framework is particularly important in the context of accounting and blockchain implementation, as it makes it possible to integrate technological parameters, organizational resources, and external institutional conditions into a single analytical framework. This makes it a relevant tool for studying the digital transformation of accounting systems.

Blockchain Technology Adoption in Accounting

Accounting is a fundamental element in the functioning of any organization, ensuring the systematization and interpretation of financial and economic information regardless of the scale or specific nature of its activities. The main functions of accounting include recording and classifying transactions, aggregating data, preparing reports, and analytically interpreting performance results. Traditional accounting systems, including paper-based systems, are characterized by several significant limitations, including delays in recording transactions, the need to carry out complex reconciliation procedures, and an increased risk of duplicate entries. Notably, many of these problems persist even in modern information systems despite their digital nature. In existing practice, each organization records financial transactions within its own information database, reflecting business events from the perspective of a specific entity. This approach leads to data fragmentation and requires additional mechanisms for reconciling information among participants in economic relations. Blockchain technology offers an alternative model for organizing accounting, based on the principles of decentralization and direct peer-to-peer interaction among participants. It is a tamper-resistant digital ledger designed to record transactions and other objects of economic value. A fundamental distinction of blockchain is its ability not only to exchange information but also to transfer value among participants without the involvement of intermediaries. In the context of accounting, this means the creation of a single, synchronized ledger that ensures a high level of data reliability and transaction transparency. The functional potential of blockchain covers all stages of the accounting process, including transaction initiation, processing, authorization, recording, and the subsequent preparation of reports. Owing to these characteristics, the technology has the capacity to profoundly transform existing models of accounting practice and improve the efficiency of financial information.

The Mediating Role of TOE Factors in Blockchain Adoption

Within the TOE framework, the factors influencing technology adoption are traditionally grouped into three key categories: technological, organizational, and environmental. This

approach makes it possible to comprehensively assess the conditions under which innovative solutions are integrated into an organization's activities. The technological context includes the set of solutions used within an organization, covering both information systems already implemented and potential technologies being considered for adoption. The organizational context reflects a company's internal characteristics, including resource availability, scale of operations, and features of its management structure. The environmental context, in turn, is determined by the conditions in which the organization operates, such as industry-specific characteristics, the regulatory environment, and the competitive landscape. In the present study, it is assumed that trust in blockchain technology influences its adoption not directly, but through the set of TOE factors. In other words, the level of trust strengthens or weakens the effect of technological, organizational, and external conditions, thereby shaping an organization's readiness to adopt the innovation.

Technological Factors of Adoption

Despite its controversial nature and potentially transformative impact, blockchain is regarded as a promising technology for modernizing accounting systems. Its key advantage lies in its ability to radically change existing approaches to processing and storing financial information by ensuring a higher level of transparency, reliability, and automation. The analysis of academic literature and empirical data made it possible to identify two basic technological factors determining blockchain adoption: relative advantage and uncertainty. On the one hand, blockchain is perceived as a technology capable of significantly improving the efficiency of accounting processes by reducing costs, simplifying procedures, and eliminating excessive intermediary links. On the other hand, a high degree of uncertainty remains, associated with technological maturity, institutional adaptation, and changes in traditional accounting practices. Thus, when assessing the feasibility of adoption, it is necessary to consider the balance between expected benefits and accompanying risks.

Relative Advantage as an Adoption Factor. Relative advantage is defined as the degree to which a new technology is perceived as more effective than existing solutions. This indicator plays a key role in the innovation adoption process, as it reflects the expected value of implementation for an organization. In the context of accounting, the advantages of blockchain technology are reflected in several characteristics, including the immutability of records, a high level of security, transaction transparency, and faster transaction processing. These features create the prerequisites for improving the quality of financial information and reducing operational risks. Existing studies on the adoption of information technologies confirm that the perception of relative advantage has a direct positive influence on innovative decision-making.

The Mediating Role of Relative Advantage

Assessing the advantages of a new technology compared with traditional systems is a critically important element of the adoption process. In the case of blockchain, this assessment is closely related to the level of trust in the technology, since its architecture is originally designed to incorporate built-in mechanisms for ensuring data reliability. The decentralized nature of blockchain and the absence of the need for intermediaries form a new model of trust based on algorithmic and cryptographic principles. This makes it possible to create integrated accounting systems with an immutable transaction history and built-in audit mechanisms. An additional aspect is the development of the concept of triple-entry accounting, in which information about business transactions is recorded simultaneously by all network participants and confirmed through consensus mechanisms. This approach strengthens control and increases the transparency of

accounting data. Taken together, these characteristics create a significant relative advantage for blockchain-based solutions. Consequently, a higher level of trust in the technology strengthens the perception of its advantages, which, in turn, increases the likelihood of its adoption in accounting practice.

CONCLUSION. The study demonstrates the significant influence of trust in blockchain technologies on organizations' readiness to introduce innovations in accounting. The results confirm that technological, organizational, and environmental factors within the TOE framework play a mediating role in the decision-making process. The analysis of respondents' profiles showed that most participants had substantial professional experience, exceeding 10 years, as well as high qualifications in accounting and information technology, which contributed to the reliability of the data obtained. Control variables, such as firm size, users' IT competencies, and industry sector, additionally revealed variation in organizations' readiness to adopt blockchain. The partial least squares method, or PLS, confirmed the validity and reliability of the measurement models, producing high values for Composite Reliability, ranging from 0.869 to 0.970, AVE, ranging from 0.735 to 0.941, and Cronbach's alpha, ranging from 0.718 to 0.938. These results confirm the accuracy of the instruments used to measure the constructs under investigation. Overall, the findings suggest that the successful implementation of blockchain systems in accounting depends not only on the technical characteristics of the technology but also on organizational readiness, top management support, and pressure from the external environment, including competitors and trading partners. These conclusions may serve as guidance for organizations seeking to improve the efficiency and transparency of accounting through the adoption of advanced technologies, while also contributing to the development of evidence-based recommendations for practitioners and policymakers.

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TRANSPORT INFRASTRUCTURE ASSESSMENT CRITERIA AND ANALYSIS

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Abstract. *This article examines the role of transport infrastructure and logistics performance in ensuring sustainable economic growth. The study analyzes the Logistics Performance Index (LPI) indicators of Central Asian countries, Turkey, and the world for the period 2007–2025. Special attention is given to key LPI components, including customs efficiency, infrastructure quality, international shipments, logistics service quality, cargo tracking, and timeliness of delivery. The results show that Central Asian countries remain below the global average in logistics performance, while Turkey demonstrates comparatively higher indicators due to its developed transport infrastructure and strategic position as a Eurasian transport hub. The analysis also reveals that Uzbekistan and Tajikistan have considerable growth potential, although access to international markets and transport corridors remains a major challenge. The article concludes that modernization, digitalization, investment attraction, and institutional reforms are essential for improving logistics efficiency and strengthening international competitiveness.*

Keywords: *logistics, transport infrastructure, Logistics Performance Index, sustainable economic growth, international trade, digitalization, Central Asia.*

Introduction

Time has transformed global technology, and over more than half a century since the Second World War, the world has witnessed extremely rapid economic development, as well as dynamic and adaptive progress. At the same time, human society has faced serious threats: in industrially developed countries, shortages of resources and infrastructure problems have emerged, while in developing countries, the pressures of population growth and development have intensified. Global economic development inevitably creates serious problems related to its environmental and ecological impact in both industrialized and developing countries. The historical experience of the past fifty years shows that economic growth cannot be achieved without the sustainable use of natural resources, environmental protection and preservation, effective use of time, and ecological awareness. Sustainability is a major economic, ecological, and social challenge for future economic development.

Sustainable economic growth refers to the consistent, balanced, and crisis-free development of an economy over a long period of time. Therefore, internal and external, political-economic, and social problems inevitably affect such a situation. Global challenges, including crises in the world economy such as pandemics, inflation, and geopolitical tensions, have been occurring frequently. Resources are limited, and environmental problems have reached a high level. Social inequalities are also increasing in societies.

Sustainable economic growth is important for the following reasons: ensuring economic stability, including inflation control, unemployment reduction, continuity of economic strategy, and stabilization of the national currency; improving the well-being of the population, including ensuring and increasing income equality, reducing poverty, and improving healthcare and

education; using resources efficiently, including resource conservation, maintaining ecological balance, and reducing the transportation of resources; and creating convenient infrastructure in all sectors.

Literature Review

The issue of the impact of transport infrastructure on economic development has been widely studied in international scientific literature. In most studies, the transport system is regarded as the main driver of economic growth. For example, in his work, D. Aschauer emphasizes that public investment in transport infrastructure is one of the most important factors increasing production productivity. Also, a World Bank report indicates that the development of transport infrastructure is of decisive importance in increasing trade volume, reducing logistics costs, and strengthening regional integration.

If attention is paid to the experience of developed countries, the high level of organization of transport and logistics infrastructure in Germany and Japan serves the stable and regionally balanced development of the economy. In particular, according to OECD data, investments directed to transport networks ensure long-term economic efficiency and stimulate production activity even in remote regions.

In the conditions of Uzbekistan, special attention is also being paid to the development of transport infrastructure. In the “Development Strategy of New Uzbekistan for 2022–2026,” the expansion of road and railway networks and the modernization of logistics centers are defined as the main task of strengthening interregional integration. At the same time, local researchers, for example, A. G‘aniev and M. Xasanov, in their scientific works, separately emphasize the importance of transport infrastructure in reducing regional economic disparities.

In conclusion, the literature review shows that the development of transport infrastructure not only accelerates economic growth but is also regarded as an effective means of reducing interregional economic inequality.

The global transport strategy is aimed at decarbonization, sustainability, and connectivity, and it is directed toward reducing greenhouse gases by 2050 through the adoption of electric vehicles, improvement of railways, and efficient infrastructure. The main goals include supporting global trade, introducing multimodal connectivity, strengthening and increasing efficiency, and improving digital solutions to reduce environmental impact.

Methodology

Main components of the global transport strategy:

Decarbonization (Net-Zero Goals): The main focus is on the transition to electric vehicles and low-carbon fuel by 2030, with the aim of electric engines occupying 35% of the global market by 2030.

Infrastructure and connectivity: This includes the development of networks such as expanding high-speed rail, improving port capacity, and increasing freight transport efficiency.

Sustainable urban mobility: Developing public transport, pedestrian, and bicycle infrastructure in order to create healthy cities and reduce dependence on private, high-emission vehicles.

Technological innovations: Integrating intelligent transport systems (ITS) and digital logistics tools to optimize route planning and reduce transportation time.

Private sector involvement: Encouraging private investment in new technologies, infrastructure, and operational efficiency in order to develop reforms and innovations.

Main regional and global initiatives:

The United Nations Decade of Sustainable Transport (2026–2035): Aimed at implementing the Sustainable Development Goals (SDGs) related to transport, including capacity building and global policy.

CAREC Transport Strategy 2030: Aimed at connecting Central Asian countries with sustainable, high-quality infrastructure and improved trade corridors.

The European Commission's mobility strategy: Aims to double high-speed rail and increase public charging points to 3 million by 2030.

Main problems and priorities:

Reducing black carbon and GHG emissions.

Financing major infrastructure projects for connectivity.

Improving the safety, performance-based maintenance, and resilience of existing infrastructure.

Results and Discussion

Today, the modern economy is increasingly integrating from the production sector into the service sector. In this regard, the need for transport infrastructure is very high, as it is an important factor in reducing transportation costs, saving time, and improving the quality of both industrial production and services.

Current global political and economic processes show that countries that possess logistics systems and transport corridors, and are able to use them rationally, are gaining wide-ranging opportunities. In order to evaluate such indicators, the World Bank developed the "Logistics Performance Index" (LPI). This index is an analytical tool that assesses countries' logistics infrastructure, customs efficiency, speed of freight transportation, and quality of services. It measures the ease of movement of goods in international trade and the overall efficiency of the logistics system.

The LPI summarizes countries' performance across six dimensions that reflect important aspects of the logistics environment.

Six main criteria were selected for determining the Logistics Performance Index.

The first part of the LPI survey, consisting of questions 10–15, provides the initial data for the international LPI. Each respondent evaluates eight foreign markets according to the six main components of logistics performance. The eight countries are randomly selected based on the most important export and import markets of the country where the respondent is located. For landlocked countries, neighboring countries that form part of the land bridge connecting them with international markets are selected. The method used to select several countries evaluated by each respondent depends on the characteristics of the country where the respondent is located (Table 1).

Respondents complete the questionnaire online. It includes the random approach of Uniform Sampling in order to obtain the most possible responses from low-income countries [Ministry of Transport of the Republic of Uzbekistan – Open data on logistics performance – https://mintrans.uz/lpi].

Since the survey mechanism mainly relies on a special country selection methodology for respondents based on high trade volumes between countries, the random approach of Uniform Sampling can help countries with low trade volumes move to the first position in country selection. After 200 surveys, the random approach of Uniform Sampling is included in the country selection mechanism process. For each new survey respondent, the random approach of Uniform Sampling requests a response from a randomly selected country, but with unequal probability, using selected

weights to convert the selection into a uniform probability. In particular, country *i* is selected with the probability *(N – ni) / 2N*, where *ni* is the sample size of country *i* so far, and *N* is the total sample size.

Table 1. Criteria for Assessing the Logistics Performance Index

Developed by the author based on World Bank data

Criteria	**Characteristics**	**Importance**	**Number of questions used in assessment**	**Weight by LPI components**	**Rating indicators (1–5)**
Customs	Efficiency of customs and other control authorities.	Important for policy-making.	10	0.4	1 – very slow; 2 – low; 3 – medium; 4 – good; 5 – very fast and efficient
Infrastructure	Quality of trade and transport infrastructure, including ports, railways, and roads.	An important indicator for attracting investment in logistics infrastructure.	11	0.42	1 – undeveloped; 2 – unsatisfactory; 3 – average; 4 – good; 5 – highly developed
International shipments	Ease of arranging international shipments at competitive prices.	Helps countries identify and improve gaps in the logistics system.	12	0.4	1 – very expensive and difficult; 2 – difficult; 3 – average; 4 – convenient; 5 – very convenient and inexpensive
Logistics quality	Quality and competence of logistics services, including transport operators and customs brokers.	Countries with well-developed logistics systems have higher competitiveness in international trade.	13	0.42	1 – low; 2 – unsatisfactory; 3 – average; 4 – good; 5 – professional and high-quality

Criteria	Characteristics	Importance	Number of questions used in assessment	Weight by LPI components	Rating indicators (1–5)
Tracking	Ability to track and trace shipments.	Assesses the possibility of using modern IT technologies and artificial intelligence.	14	0.41	1 – not available; 2 – limited; 3 – partial; 4 – close to real time; 5 – full real-time tracking
Timeliness	Arrival of shipments within the scheduled time.	Assesses agreements, trust, and the indicator of being a strategic partner in international trade.	15	0.4	1 – always delayed; 2 – often delayed; 3 – sometimes delayed; 4 – mostly on time; 5 – always on time

The international LPI is a general indicator of the performance of the logistics sector, combining data on six main performance components into a single overall indicator. Some respondents did not provide data for all six components; therefore, interpolation is used to fill in the missing values. Missing values are replaced by the average national value of responses for each question, adjusted according to the respondent's average deviation from the national average in their answers to the questions. As can be seen from the table, during the period from 2007 to 2025, logistics performance indicators in Central Asian countries have remained at a relatively low level. At the same time, the average "World" indicator increased from 2.7 to 3.0, which means that logistics systems are steadily developing at the global level. Based on the diagram, it can be concluded that Kazakhstan's LPI index increased sharply from 2.1 in 2007 to 2.8 in 2010. In the following years, it stabilized at around 2.7–2.8. This indicates that the country developed its logistics infrastructure relatively quickly. The Kyrgyz Republic reached 2.6 in 2010, but later a decline was observed, and by 2025 it recovered to 2.5. From the dynamics of this indicator, it can be concluded that the logistics system is not stable and is sensitive to external factors. In other words, there are strong dependencies in foreign policy. In Tajikistan, there is an overall increase in the LPI index from 1.9 to 2.5. However, across the years, there is a slow but positive development trend. In Turkmenistan, LPI index data are not complete, but on average they are in the range of 2.2–2.5. The situation is stable, but high growth is not observed. The reason is that a relatively closed political system is observed in this country, and it conducts a policy dependent on the influence of neighboring countries. However, among Central Asian countries, the most convenient transport infrastructure exists in this territory. The conditions for access to the Caspian Sea, the opportunity to reach large markets through it, and the possibilities of access to the ocean through Pakistan and Iran are higher compared to the remaining countries.

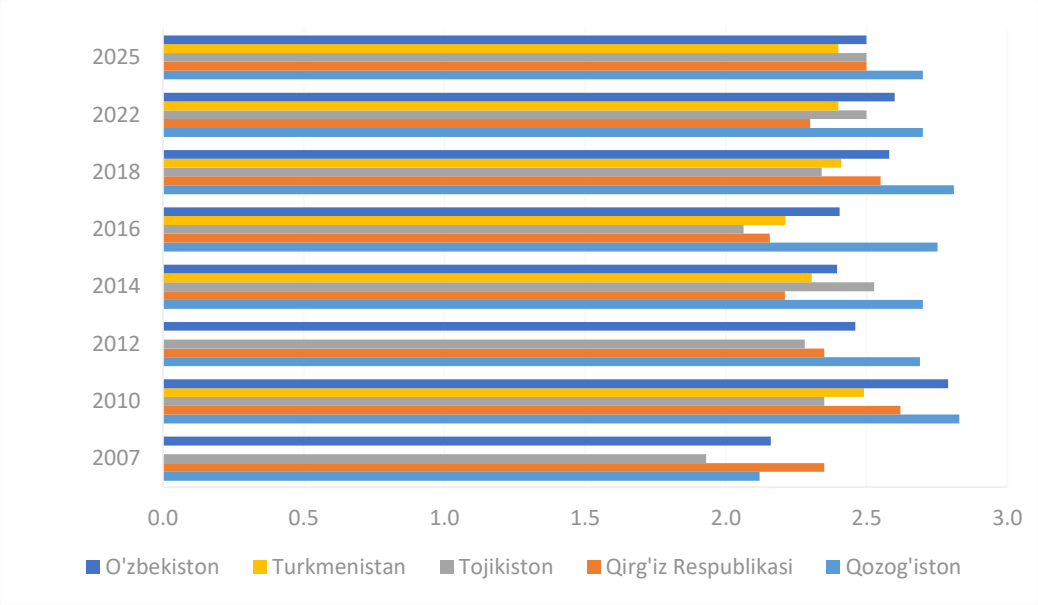


Figure 1. Logistics Performance Index (LPI) by Years

Developed by the author based on World Bank data

In Uzbekistan, the LPI index reached its highest point in 2010, up to 2.8. However, later it stabilized in the range of 2.4–2.6. In recent years, growth has slowed down, but there has been no decline. For Uzbekistan, access to the ocean is considered a major problem, because reaching sea routes requires passing through two countries. At the same time, in the south, the unstable situation in Afghanistan does not provide a guarantee for security, while Turkmenistan is a closed territory. In the north, there is an opportunity to access the ocean through Kazakhstan and Russia, but since the market where our products can compete has formed in the south, this route is long. Therefore, our opportunity to access the ocean through Russia remains possible only with goods that meet the quality standards of the European Union. In other words, with high-quality goods.

Table 2. Comparative Analysis of the Logistics Performance Index (LPI) of Central Asian Countries, Turkey, and the World in 2007–2025

No.	Countries	2007	2010	2012	2014	2016	2018	2022	2025
1	Kazakhstan	2.1	2.8	2.7	2.7	2.8	2.8	2.7	2.7
2	Kyrgyz Republic	2.4	2.6	2.4	2.2	2.2	2.6	2.3	2.5
3	Tajikistan	1.9	2.4	2.3	2.5	2.1	2.3	2.5	2.5
4	Turkmenistan	—	2.5	—	2.3	2.2	2.4	2.4	2.4
5	Uzbekistan	2.2	2.8	2.5	2.4	2.4	2.6	2.6	2.5
6	Turkey	3.2	3.2	3.5	3.5	3.4	3.2	3.4	3.4
7	World	2.7	2.9	2.9	2.9	2.9			

In Table 2, we analyzed the general LPI index of Turkey and the world in order to conduct a comparative analysis with Central Asian countries. The analysis of Central Asian countries, including Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, and the Kyrgyz Republic, was presented above. The reason we included Turkey in this analysis is that it is ethnically related to Central Asian countries, and it is also interesting because of its geographical location and its policy as a bridge connecting Eurasia. In this regard, Turkey's establishment of a "transport hub" in Istanbul provides the country with advantages in foreign trade, domestic trade, and politics for

many years. At the same time, Turkey has the highest indicators, ranging from 3.2 to 3.5. It has a developed logistics system and transport infrastructure, and its result is better than the world average LPI. This indicates that the country has paid more attention and invested more in transport infrastructure than the average level. However, according to the LPI indicator, it is not among the very best countries. For example, in such a table, Singapore ranks first in the world with an LPI index of 4.3, while Finland ranks second with an index of 4.2. Hong Kong is in 10th place among the top 10 with an index of 4.0.

In comparison, Central Asian countries are below the world average level in terms of LPI. The most stable country in the region is Kazakhstan. The countries with the greatest growth potential are Uzbekistan and Tajikistan. In recent years, the strengthening of good-neighborly relations and economic cooperation in the development of these countries' economies has had a positive impact on economic indicators.

These data show the following:

First, logistics infrastructure is still at the stage of development. Many investments and institutional changes need to be introduced into this sector.

Second, transport, the customs system, and the level of digitalization are important factors. Today, all studies on the application of IT in the transport sector show positive correlations.

Conclusion and Recommendations

The analysis conducted above shows that the efficiency of the logistics system is one of the important factors in the economic development of a country. In particular, the speed of customs procedures, the level of development of transport and trade infrastructure, international freight transportation opportunities, the quality of logistics services, cargo tracking systems, and timely delivery are considered the main criteria determining logistics efficiency.

As a result of the analysis, it was identified that these indicators directly determine not only the internal efficiency of the logistics system but also the country's competitiveness in international trade. In particular, the level of use of modern information technologies and artificial intelligence is of great importance in optimizing logistics processes, reducing costs, and improving the quality of services. At the same time, applying a comprehensive approach in assessing the logistics system, that is, analyzing all criteria on the basis of a single system, makes it possible to compare countries and serves to identify existing problems and develop effective strategies for eliminating them. In general, sustainable economic growth of the country can be ensured through the development of the logistics system, modernization of infrastructure, acceleration of digitalization processes, and deepening of institutional reforms. Based on the analysis conducted, in order to increase the efficiency of the logistics system and strengthen its international competitiveness, it is appropriate to put forward the following proposals and recommendations.

First, customs procedures should be further simplified and digitalized. In particular, the wide introduction of electronic declaration systems and the development of risk management systems based on artificial intelligence can reduce the time required for cargo clearance.

Second, the modernization of transport and logistics infrastructure is of great importance. The efficiency of freight transportation can be significantly increased through the development of railways, highways, logistics centers, and warehouse systems.

Third, in order to increase competitiveness in the international freight transportation market, it is necessary to optimize the prices of logistics services and diversify transport routes. This, in turn, will contribute to the expansion of foreign trade volume.

Fourth, in order to improve the quality of logistics services, it is necessary to develop the system of training qualified personnel and improve the professional competencies of transport operators and customs brokers.

Fifth, it is necessary to improve cargo tracking systems and introduce digital platforms that allow real-time monitoring. Through this, the transparency and reliability of logistics processes can be increased.

Sixth, in order to ensure the timely delivery of cargo, it is appropriate to optimize logistics chains, integrate transport and logistics operations, and apply modern management methods.

Seventh, the overall efficiency of the system can be increased by developing cooperation between the state and the private sector in the logistics system, attracting investments, and widely introducing innovative technologies.

In general, the practical implementation of the above recommendations will serve to ensure the sustainable development of the logistics system, expand the volume of foreign trade, and increase the country's competitiveness in the international economic arena.

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PROSPECTS FOR THE DEVELOPMENT OF ENTREPRENEURSHIP IN THE PHARMACEUTICAL SECTOR OF THE REPUBLIC OF UZBEKISTAN

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https://doi.org/10.5281/zenodo.20067911

Abstract. *This article analyzes the prospects for the development of entrepreneurship in the pharmaceutical sector of Uzbekistan on the basis of factual and regulatory-legal sources. In particular, it examines presidential decrees and resolutions adopted in 2017-2023 to support the pharmaceutical industry, the policy of regional clustering of the sector, the activities of free economic zones, the level of localization, investment processes, and export indicators. In addition, based on data from the World Health Organization (WHO), the World Bank, and other international sources, the institutional and economic factors for the development of pharmaceutical entrepreneurship in Uzbekistan are discussed.*

Keywords: *pharmaceutical industry, entrepreneurship, free economic zone, investment, localization, export, pharmaceutical market, pharmaceutical cluster.*

Introduction

The pharmaceutical industry is considered one of the sectors of the national economy that creates high added value and has innovative and social significance. According to the World Health Organization, the stability of the healthcare system largely depends on the uninterrupted supply of medicines and medical products [1, p. 12].

In Uzbekistan, the development of the pharmaceutical sector has been identified as one of the priority areas of state policy. The Decree of the President of the Republic of Uzbekistan “On the Strategy of Actions for the Further Development of the Republic of Uzbekistan” (2017-2021) defined tasks related to the modernization of economic sectors and the expansion of domestic production. The decree approved the Strategy of Actions for 2017-2021. The strategy consists of five key priority areas and a clear program of measures for their implementation [2, p. 15].

By Decree No. PF-5032 of January 23, 2017, the management system of the pharmaceutical industry was fundamentally improved, and the state joint-stock company “O‘zfarmsanoat” was established [3, p. 3]. This document created the institutional foundation for the development of pharmaceutical entrepreneurship. According to the Statistics Agency, by the end of 2022, more than 200 pharmaceutical enterprises were operating in the republic, and 212 pharmaceutical production facilities were registered. These enterprises are engaged in the production of medicines, medical equipment, and other related products [4, p. 48]. This shows that the number of entrepreneurial entities in the sector is increasing. As of 2026, more than 300 pharmaceutical enterprises were reported, and 58 of them were directly engaged in product manufacturing. This growth is associated with a 3.5-fold increase in the volume of medicine production and an expansion in the number of products supplied to the domestic market and for export.

Methodology

In the research process, methods of analysis of regulatory legal documents, comparison of official statistical data, systemic analysis, and comparative analysis were used.

The following were used as the main sources:

- decrees and resolutions of the President of the Republic of Uzbekistan [2; 3; 5];
- data from the State Statistics Committee [4];
- reports of the World Bank and WHO [1; 6];
- data from the Ministry of Investments and Foreign Trade [7].

During the analysis, dynamic indicators for 2017-2023 were studied. It was noted that the share of industry in GDP increased; for example, the share of all industrial enterprises in GDP rose from 21.1% to 26.7%. This indicates growth in pharmaceutical production and an increase in the strategic role of the sector in industry. Dynamic indicators for 2017-2025 were also examined, and the share of the pharmaceutical industry in GDP, the volume of investments, and export potential were assessed. Official annual data do not present a separate detailed statistic on the exact share of the pharmaceutical industry in GDP. However, according to general analytical sources, in 2023, exports of pharmaceutical products accounted for approximately 2.6% of Uzbekistan's total trade volume, which demonstrates the growing role of the sector in the economy. In general, the contribution of pharmaceutical production to GDP is also increasing, because indicators for production, exports, and investment in the sector are growing. However, official statistics on the sector's GDP share are not presented as a separate line in annual reports.

Production volume:

- Significant growth: from 2017 to 2024-2025, production more than doubled and is expected to reach a capacity of more than 6 trillion UZS.
- **Number of enterprises:**
- Growth: 146 enterprises in 2017, 195 in 2024, and around 300 or more entities operating in the sector by 2025.
- **Exports and trade:**
- Exports of products increased more than tenfold, and the sector expanded its presence in the global market.
- **Investments:**
- Foreign and domestic investments are increasing, while the introduction of innovations and standards is strengthening.

Results

Since 2017, a number of free economic zones have been established in the pharmaceutical sector. In particular, the "Nukus-pharm," "Zomin-pharm," "Kosonsoy-pharm," "Sirdaryo-pharm," and "Boysun-pharm" free economic zones were created on the basis of presidential resolutions [5, p. 2].

Tax and customs privileges were introduced in these zones. According to the resolution, depending on the amount of investment, tax benefits are provided for a period from 3 to 10 years [5, p. 4]. According to the Statistics Agency, in 2021 the volume of pharmaceutical production increased almost twofold compared with 2016 [4, p. 52]. On the basis of available statistical data, it can be stated that in Uzbekistan, by 2025, the volume of pharmaceutical production had increased considerably compared with the 2017-2024 period. Some sources indicate that the increase was even higher compared with 2016.

For 2016, a number of statistical data exist concerning pharmaceutical production in Uzbekistan. By the end of 2016, the volume of pharmaceutical production was approximately

711.4 billion UZS. In 2025, the volume of pharmaceutical production reached 6.3 trillion UZS, compared with 5.1 trillion UZS in 2024. The volume of investment also increased. According to the Ministry of Investments and Foreign Trade, in 2019-2022 the volume of direct foreign investment attracted to the pharmaceutical industry showed significant growth [7, p. 37]. In 2019-2025, the volume of direct financial investments attracted to the pharmaceutical industry increased gradually and formed, on average, around 0.5-1 billion USD per year, showing an upward trend in overall investment capacity. In addition, in 2019 the process of registering medicines in Uzbekistan was simplified, and the introduction of GMP (Good Manufacturing Practice) standards began to be implemented gradually [3, p. 6]. According to WHO, production in accordance with GMP standards is a key factor in ensuring the quality of medicines [1, p. 28].

Analysis and Discussion

The prospects for the development of entrepreneurship in the pharmaceutical sector in Uzbekistan are determined by complex economic, institutional, and organizational factors. In recent years, state policy aimed at supporting the sector has been implemented through the improvement of the regulatory framework, improvement of the investment environment, and stimulation of local producers. These processes began with the reform of the pharmaceutical industry management system based on Decree No. PF-5032 [3, p. 3]. This document provided for the gradual transition of the sector from a centralized management model to an effective corporate governance system, optimization of licensing and registration processes, and support for investment projects. The stabilization of the regulatory legal environment formed clear “rules of the game” for business entities. In particular, the Law “On Medicines and Pharmaceutical Activity” defines the basic principles of pharmaceutical activity, licensing procedures, and quality control mechanisms [12, p. 7]. This served to legally guarantee the market-entry opportunities of private sector representatives. The policy of territorial clustering has emerged as an important factor in the development of pharmaceutical entrepreneurship. In the pharmaceutical free economic zones established in accordance with the presidential resolution, privileges were provided in taxation, customs, and currency operations [5, p. 4]. These privileges were designated to be applied in a differentiated manner depending on the amount of investment. Analyses show that territorial specialization helps reduce infrastructure costs, increase logistics efficiency, and strengthen production cooperation [10, p. 57].

The specific situation regarding pharmaceutical clusters is as follows: by 2026, the largest example is the “Tashkent Pharma Park” pharmaceutical cluster, which is being transformed into BioPharma City, a biotechnology center. With the help of this cluster, new production and scientific centers are being added.

These indicators are explained by the establishment of new enterprises in the sector and the expansion of existing production capacities. At the same time, the share of small business entities in the industrial structure remains high, which shows that pharmaceutical entrepreneurship is developing mainly at the expense of the private sector.

Import substitution policy has strategic importance in the pharmaceutical sector. In 2016, the main part of the medicines in the domestic market was supplied through imports [4, p. 60], while in subsequent years programs were implemented to increase the share of domestic production. In this process, giving priority to domestic producers through the public procurement system served as an important mechanism.

Changes in the share of domestic production:

- 2016-2017: most of the market was filled by imports, approximately 70-80%; the share of domestic production was around 20-30%; the number of enterprises was small and the technological base was limited.
- 2018-2020: state support for the pharmaceutical industry began; new facilities and clusters were established; the share of domestic production increased to 30-40%, while the import share gradually began to decrease.
- 2021-2023: the industry was modernized through the cluster system and investments; the assortment of local medicines expanded; the share reached 40-55%, and in certain segments, especially simple generic drugs, domestic production became predominant.
- 2024-2025: new pharmaceutical facilities were launched; the policy of import substitution intensified; the share of local production reached around 55-65% and was even higher in some directions, although imports still remained in complex and original drug programs.

However, as noted in the World Bank report, the pharmaceutical industry is highly capital-intensive and requires large amounts of funding for research and innovation activities [6, p. 44]. In the pharmaceutical industry, the development of a new medicine requires billions of dollars and many years of research. For example, one new medicine may require 1-2 billion USD and 10-15 years, which demonstrates the high capital intensity of the sector. This creates financial restrictions for small business entities. From this point of view, there is a need to expand preferential lending and grant mechanisms by the state.

Preferential lending systems for enterprises can be described as follows:

Direction	Provided through	Conditions	Benefits	Where applied
State bank loans	UzSanoatQurilishBank, Asaka Bank, Agrobank, Xalq Bank	Project-based	Low interest and long terms (3-7 years)	Industry and production
Investment loans	State and foreign banks	Large projects	Interest subsidies and guarantees	New plants and clusters
Pharmaceutical sector loans	Banks and state programs	GMP standards are required	Tax and credit privileges	Tashkent Pharma Park and clusters
Small business loans	Commercial banks	Small enterprises	Subsidized rates of 5-18%	Startups and small-scale production
Innovation loans	Innovation institutions	Research and development	Grants and preferential mechanisms	New developments and innovative projects

The introduction of GMP standards in the production of pharmaceutical products is an important condition for entering international markets. According to WHO, GMP requirements are the main instrument for ensuring quality and safety in the production process [1, p. 28]. The increase in the number of enterprises with GMP certification in Uzbekistan creates a basis for expanding export potential. The analysis of export indicators shows that in 2022 exports of pharmaceutical products demonstrated a growth trend [4, p. 64]. In 2026, Uzbekistan’s

pharmaceutical exports are expected to show a growth trend, exceed the approximately 32 million USD level of 2025, and develop with accelerated growth due to entry into new markets. Neighboring countries are being formed as priority markets in this process. The Asian Development Bank report notes that regional trade integration is an important factor in expanding exports of pharmaceutical products [10, p. 58].

At the same time, dependence on imported raw materials remains a relevant issue. According to WHO reports, in developing countries, the main part of active pharmaceutical ingredients is imported [1, p. 31]. Pharmaceutical enterprises in Uzbekistan also often rely on substances imported from abroad. This increases sensitivity to exchange-rate fluctuations and affects production costs. By 2026, pharmaceutical raw materials in Uzbekistan are expected to be imported mainly from India, China, Russia, and European countries. Their volume is estimated at around 700 million to 1.2 billion USD, indicating that the sector remains highly dependent on imports. According to UNIDO, establishing a full production cycle in pharmaceutical manufacturing requires long-term investment and scientific capacity [11, p. 35]. Therefore, along with deepening localization policy, the development of the chemical industry and biotechnology is of great importance.

Integration between research institutes, higher education institutions, and production is an important condition for the development of innovative entrepreneurship. Decree No. PF-5032 of January 23, 2017, set tasks for supporting the implementation of scientific developments in practice and the creation of new medicines [3, p. 8]. This makes it possible to strengthen the “science - production - market” chain.

In 2017-2025, the following changes were observed in Uzbekistan:

- the number of scientific developments increased;
- patenting and innovation activity intensified;
- the science - production - market chain began to take shape;
- the production of new products expanded;
- pharmaceutical clusters became centers of scientific innovation.

Investment dynamics also show a positive trend. According to the Ministry of Investments and Foreign Trade, in 2019-2022 the volume of direct foreign investments directed to the pharmaceutical industry increased [7, p. 39]. In 2019-2025, direct economic investments directed to the pharmaceutical industry in Uzbekistan increased gradually and amounted in total to around 0.3-1 billion USD, with investment activity reaching its highest stage in 2025. The participation of foreign investors accelerates the transfer of modern technologies and serves to bring product quality up to international requirements.

The following can be indicated as the problems of pharmaceutical entrepreneurship:

High dependence on imported raw materials:

- Many active pharmaceutical ingredients (APIs) are supplied from abroad.
- Local raw materials are insufficient.
- Exchange-rate fluctuations affect production costs.
- As a result, small enterprises face difficulties.

Financing and access to credit:

- Collateral requirements are high.
- Long-term low-cost loans are insufficient.
- Risk capital for innovative projects is limited.
- This is a major barrier for small businesses.

Lack of modern technology:

- Equipment meeting GMP standards is expensive.
- The R&D base is weak.
- Biotechnological production processes are insufficiently developed.

Complexity of certification and licensing:

- Registration of medicines takes a long time.
- Adaptation to international standards is difficult.
- Inspection and permitting procedures are multi-stage.

Competition and market problems:

- Competition with imported medicines is strong.
- Large firms occupy significant parts of the market.
- Market entry is difficult for small entrepreneurs.

Shortage of personnel:

- There are few pharmaceutical engineers and technologists.
- Practical experience is insufficient.
- Innovative thinking is weakly developed.

Weak export infrastructure:

- Logistics services are expensive.
- Opportunities to enter foreign markets are limited.
- Certificates and standards do not always correspond to foreign requirements.

Regulatory and institutional problems:

- Legislation changes frequently.
- It is difficult for entrepreneurs to make forecasts.
- Some procedures are bureaucratic in nature.

Analyses show that the prospects for the development of entrepreneurship in the pharmaceutical sector depend on the following factors:

- stability of the regulatory legal environment;
- improvement of investment and financing mechanisms;
- localization and import substitution policy;
- increase in research and development capacity;
- diversification of export markets.

In addition, modernization of the healthcare system increases domestic demand for pharmaceutical products. The World Bank report notes that investment in healthcare infrastructure ensures stable growth of the pharmaceutical industry in the domestic market [6, p. 47].

In general, institutional and economic foundations have been formed for the development of entrepreneurship in the pharmaceutical sector in Uzbekistan. However, high-technology production, strengthening scientific potential, and expanding the raw-material base remain priority tasks for the future. In this process, international cooperation, technology transfer, and the establishment of innovative clusters play an important role.

Conclusion and Recommendations

A strong regulatory and legal foundation has been created for the development of entrepreneurship in the pharmaceutical sector in Uzbekistan. In 2017-2023, the establishment of free economic zones, the provision of tax benefits, the introduction of GMP standards, and the improvement of the investment environment had a positive impact on the development of the sector.

In 2023-2025, the pharmaceutical industry in Uzbekistan was characterized by growth in industrial production volume, expansion of production capacity, development of investments and clusters, and expansion of export geography. During this period, the sector moved toward import substitution and innovative business development.

At the same time, we believe that the development of high-technology production, expansion of the raw-material base, commercialization of research developments, and expansion of export geography will remain priority directions for the future development of pharmaceutical entrepreneurship.

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ENSURING MONETARY CIRCULATION STABILITY THROUGH THE DEVELOPMENT OF DIGITAL PAYMENT SYSTEMS: A COMPREHENSIVE ANALYSIS BASED ON SCIENTIFIC INNOVATIONS

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https://doi.org/10.5281/zenodo.20067669

Abstract. *This scientific article examines the impact of the development of digital payment systems on the stability of monetary circulation based on a comprehensive approach. The study analyzes four key scientific innovations proposed within the dissertation framework—mandatory cashless payments for large-value transactions, full digitalization of real estate and vehicle transactions, electronic implementation of utility payments, and the introduction of a unified QR-code system—using the IMRAD methodology. Econometric modeling, statistical, and comparative analysis methods were applied, and empirical data were used to assess the impact of digital payment systems on money circulation velocity, monetary aggregate structure, and financial flow transparency. The results indicate that the widespread adoption of digital payment systems contributes to reducing the share of cash, lowering the level of the shadow economy, increasing tax revenues, and strengthening the effectiveness of monetary policy. The study also identifies existing challenges in digital payment infrastructure development and provides directions for their mitigation.*

Keywords: *digital payment systems, monetary circulation stability, cashless payments, econometric analysis, financial inclusion, shadow economy, QR-code system, monetary policy, financial transparency, digital economy.*

INTRODUCTION

In the global economy, the rapid development of digital technologies has led to the transformation of financial systems, particularly facilitating a qualitative shift in monetary circulation and payment systems. The increasing share of cashless payments serves as a key factor in enhancing the transparency of economic transactions, reducing transaction costs, and improving the effectiveness of monetary policy. In the Republic of Uzbekistan, ongoing reforms aimed at developing the digital economy, modernizing the banking system, and reducing the share of the informal economy require the development of new mechanisms to ensure monetary stability. In this regard, the scientific analysis of factors influencing monetary circulation stability through the development of digital payment systems, as well as a systematic study of the scientific innovations proposed in the dissertation, represents an urgent research task.

MATERIALS AND METHODS

The research methodology is based on a multi-stage integrated approach, combining theoretical, empirical, and econometric methods. In the theoretical stage, the economic essence of digital payment systems, their relationship with monetary circulation, and their impact mechanisms on financial stability were studied using logical analysis and scientific generalization methods. A conceptual model was developed based on a systemic approach, reflecting the

interrelations between digital payment infrastructure, transmission channels, and monetary indicators.

In the empirical analysis stage, a database of official statistical information for the Republic of Uzbekistan was formed, and time-series analysis was conducted. In particular, the dynamics of cashless payment share, money circulation velocity, monetary aggregates (M0, M1, M2), inflation rate, and shadow economy share were examined. Based on these data, trend analysis, growth rates, and structural changes were identified, and the macroeconomic impact of digital payment system development was assessed.

In the econometric stage, regression models were constructed to determine the relationship between digital payments and monetary circulation stability. Independent variables included the share of cashless payments, digital transaction volume, and payment infrastructure indicators, while dependent variables included money circulation velocity, inflation rate, and monetary balance indicators. Statistical significance of parameters was tested using t-tests and F-tests, and model adequacy was evaluated using the coefficient of determination (R^2). Additionally, correlation analysis was used to examine interdependencies among variables.

Within the institutional analysis framework, regulatory mechanisms governing digital payment systems, the level of integration between banks and payment organizations, and the effectiveness of state policy measures were assessed. In particular, the institutional foundations of innovations such as mandatory cashless payments for large transactions, digitalization of real estate and vehicle transactions, electronic utility payments, and the unified QR-code system were thoroughly analyzed.

In the forecasting stage, extrapolation and scenario analysis methods were applied. Forecast indicators for 2026–2030 were developed regarding cashless payment share, shadow economy level, and tax revenues. Optimistic, baseline, and conservative scenarios were constructed, and expected economic outcomes for each scenario were evaluated. Additionally, expert assessment methods were used to identify future development prospects and potential risks of digital payment systems.

To ensure the reliability of the study, the obtained results were verified using multiple methods; statistical findings were compared with econometric modeling results to ensure consistency. Furthermore, comparative analysis with international experience was conducted to assess the generalizability and practical applicability of the scientific conclusions.

RESULTS

The results of the study confirm that the scientific innovations aimed at developing digital payment systems exert a multifaceted and systemic positive impact on the stability of monetary circulation. First of all, the introduction of a mechanism requiring mandatory cashless payments for goods and services exceeding 25 million UZS significantly increases the share of financial flows circulating through the banking system. This not only ensures transparency of monetary transactions but also contributes to the reduction of illegal cash circulation. Empirical calculations show that, as a result of implementing this mechanism, the share of cashless payments in trade and service sectors gradually increases, reaching 70–75% in the medium-term perspective. At the same time, due to increased tax revenues and formalization of economic operations, a significant reduction in the shadow economy is observed. This strengthens the internal balance of monetary circulation and enhances the effectiveness of monetary control instruments.

The full digitalization of real estate and vehicle transactions has significantly improved transparency in high-value asset markets. The introduction of real-time transaction verification

through electronic integration between banking and notary systems minimizes human involvement and sharply reduces the use of cash. The analysis shows that in this segment, the share of cashless settlements reaches an almost complete level, exceeding 95%. As a result, cases such as artificial price underreporting, informal payments, and hidden transactions are significantly reduced. This strengthens financial discipline and ensures reliability and stability in asset markets.

The mandatory digitalization of utility payments also demonstrates positive dynamics. The transition of electricity, natural gas, and water payments into electronic form leads to deeper integration of households into the banking system. As a result, control over monetary flows increases, informal cash circulation decreases, and the inclusion of the population in the formal financial system expands. Calculations indicate that these measures increase employment in the formal sector and enhance the achievement of target indicators. Furthermore, full digitalization of utility payments positively affects the stability of state budget revenues.

The implementation of a unified QR-code system demonstrates a qualitative transformation of payment infrastructure. This system enables all trade and service entities to operate under a unified standard, eliminating technological disparities between different payment applications. As a result, payment processes are simplified, transaction speed increases, and user convenience improves significantly. Most importantly, the data generated through the unified QR-code system allows real-time monitoring of financial flows, strengthening fiscal control and improving tax administration. This enhances transparency of economic operations and ensures a fair competitive environment.

Overall, the findings show that these scientific innovations in digital payment system development positively affect all key parameters of monetary circulation—money velocity, monetary aggregate structure, cash share, and financial transparency. The integrated approach leads to a reduction in cash usage and an expansion of banking-based financial flows, which is a key factor in ensuring macroeconomic stability.

DISCUSSION

A deeper analysis of the results reveals that the development of digital payment systems is not merely a technological innovation but a comprehensive institutional and macroeconomic transformation tool for ensuring monetary stability. First, the increase in cashless payments stimulates the velocity of money circulation and contributes to the efficient distribution of liquidity in the economy. This process strengthens the transmission mechanisms of monetary policy, as control over monetary aggregates improves and the impact of Central Bank decisions on the real sector becomes faster and more effective.

In particular, the requirement for mandatory cashless payments for large transactions ensures that monetary flows are channeled through the banking system, thereby reducing shadow economic activity. Consequently, tax revenues increase, ensuring greater fiscal stability and improving the effectiveness of fiscal policy.

The digitalization of real estate and vehicle transactions plays a crucial role in ensuring institutional transparency of financial operations. Since high-value transactions constitute a significant share of monetary flows, their full control directly contributes to overall monetary stability. Integration between banking and notary systems reduces human-related errors and corruption risks. At the same time, this mechanism improves price transparency in asset markets, thereby enhancing the investment climate and supporting sustainable economic growth.

The full digitalization of utility payments deepens household integration into the financial system. Conducting daily transactions through banking channels increases financial inclusion and

strengthens control over income and expenditure flows. This reduces informal economic activity and improves the efficiency of public service delivery. Additionally, digitalization enhances accuracy in accounting and contributes to more efficient resource allocation, supporting employment growth in the formal sector.

The introduction of a unified QR-code system represents a new stage in the standardization of payment infrastructure. Integration between different payment platforms enhances competition, improves service quality, and maximizes user convenience. Moreover, the large-scale transactional data generated by this system enables real-time analysis, improving fiscal and monetary monitoring. As a result, economic transparency increases, tax administration efficiency improves, and overall economic governance becomes more effective.

However, the study also identifies several challenges. First, the uneven development of technological infrastructure across regions may limit the effectiveness of digital payment systems in certain areas. Second, increasing cybersecurity risks highlight the importance of ensuring financial data protection. Third, insufficient levels of digital literacy among the population may create social and economic barriers to the adoption of new technologies. Therefore, alongside digital payment development, comprehensive measures are required to improve infrastructure, strengthen information security, and enhance financial and digital literacy.

Overall, the results demonstrate that the development of digital payment systems is strategically important for ensuring monetary stability, increasing transparency, strengthening financial discipline, and supporting sustainable economic growth. These mechanisms can also serve as a universal model applicable not only in Uzbekistan but also in other developing economies.

CONCLUSION

In conclusion, the study scientifically substantiates that the development of digital payment systems is a strategically important and comprehensive mechanism for ensuring monetary circulation stability. The proposed scientific innovations—mandatory cashless payments for large transactions, full digitalization of real estate and vehicle transactions, electronic utility payments, and the introduction of a unified QR-code system—are interrelated and jointly contribute to all key indicators of monetary circulation. These mechanisms reduce the share of cash, expand banking-based financial flows, and enhance the transparency of financial operations, thereby serving as a crucial factor in strengthening macroeconomic stability.

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FEATURES OF THE DEVELOPMENT OF SMALL BUSINESS ACTIVITY IN THE PHARMACEUTICAL SECTOR

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https://doi.org/10.5281/zenodo.20067988

Abstract*. This article analyzes the specific features and development factors of small business activity in the pharmaceutical sector under the conditions of Uzbekistan. The study highlights the legal foundations of the sector, licensing requirements, quality and safety standards (GMP, GPP), capital intensity, innovative orientation, and social significance. It also substantiates the influence of state support mechanisms, import-substitution policy, and digital transformation on the development of small business. As a result of the study, practical recommendations for improving the sector were developed.*

Keywords: *pharmaceutical sector, small business, licensing, GMP and GPP, quality and safety, innovative development, import substitution, digitalization, pharmaceutical market, competitiveness.*

Introduction

At the present stage, in order to accelerate the implementation of the economic reforms defined in our country, state administration bodies are supporting all forms of entrepreneurial activity across all sectors [1].

In Uzbekistan, favorable conditions are being created for small business entities in the pharmaceutical sector. In addition, a number of loans and tax privileges have been introduced for small and medium-sized business entities in the Republic of Uzbekistan. Measures such as cooperation with research institutes and the introduction of innovative technologies are also ensuring the rapid growth of this sector.

The contribution of small business to the development of a market economy is very significant, because it has many advantages [2].

Research Aim

The aim of the study is to reveal the specific features of small business in the pharmaceutical field and to analyze its prospects. Within the framework of the study, practical solutions for improving the sector were also developed. The research covers the economic and legal processes of small enterprises operating in the pharmaceutical sector of Uzbekistan.

Research Methodology

The study used methods of regulatory and legal analysis, comparative analysis, a systematic approach, and generalization.

This approach made it possible to identify the specific aspects of small business activity in the pharmaceutical sector, assess the factors of its development, and substantiate its prospective directions.

Data Sources and Literature Review

In this study, regulatory and legal documents, scientific literature, and official sectoral data were analyzed in order to study the development features of small business activity in the pharmaceutical sector.

The main sources of information for the study were the Law of the Republic of Uzbekistan "On Medicines and Pharmaceutical Activity" (No. ZRU-399, 04.01.2016), as well as the Decrees of the President of the Republic of Uzbekistan No. PF-5707 dated April 10, 2019, and No. PF-20 dated January 23, 2024, aimed at the development and regulation of the pharmaceutical sector. These documents define the legal foundations of pharmaceutical activity, the licensing procedure, quality and safety requirements, and the directions for modernization of the sector.

In addition, scientific articles and economic analyses related to the development of the pharmaceutical industry were studied during the research process. In particular, scientific works devoted to the development of small business, the formation of innovative infrastructure, and the activation of human capital were used.

As an analytical base, the legal status, organizational and legal forms, licensing requirements, mechanisms of state support, and institutional development factors of small business entities operating in the pharmaceutical sector of Uzbekistan were examined.

Main Part

Before starting entrepreneurial activity in the pharmaceutical sector, a future entrepreneur should first aim to provide useful and high-quality services for public health, know the directions of pharmaceutical activity, and determine exactly in which direction they will operate.

The Law of the Republic of Uzbekistan No. ZRU-399 dated January 4, 2016, "On Medicines and Pharmaceutical Activity," defines the main directions of pharmaceutical activity. According to this law, pharmaceutical entities may carry out research and development work on the creation of medicines and medical devices, their production, quality control, wholesale and retail sale, preparation, as well as packaging of medicinal plant raw materials and their release for wholesale trade. Among these, a license is required for the following activities: production of medicines, preparation of medicines, retail and wholesale sale of medicines, and retail sale of medical devices.

The law also establishes that a license is required to carry out pharmaceutical activity. A license is usually issued for a period of five years, but, at the request of the applicant, it may also be issued for a period shorter than five years. The validity period of the license may also be extended upon the application of the licensee.

The use of medicines, medical devices, and medical equipment for medical purposes is carried out only on the basis of a registration certificate issued in the established procedure. At the same time, retail sale of ophthalmological medical devices (optics) must be carried out by notifying the authorized body [3].

It is also important for a future entrepreneur to choose the organizational and legal form of the business entity being established and to develop a medium- and long-term business strategy.

The organizational and legal form of a business entity is determined depending on the entrepreneur's available funds and goals. If sufficient initial capital is available, it is advisable to establish a limited liability company [4].

According to the Decree of the President of the Republic of Uzbekistan No. PF-5707 dated April 10, 2019, and the Decree No. PF-20 dated January 23, 2024, "On Additional Measures to Regulate the Pharmaceutical Sector," chain pharmacies must undergo mandatory certification by January 1, 2025. At the same time, by January 1, 2026, all remaining pharmacies must also obtain

mandatory certification in accordance with the national standards of "Good Pharmacy Practice (GPP)" [5,6].

Main Features of Small Business Activity in the Pharmaceutical Sector

Small business activity in the pharmaceutical sector is closely connected not only with general business principles but also with the requirements of the healthcare system and state control. The main features of this sector are as follows:

- Strict state regulation. Pharmaceutical activity is carried out on the basis of mandatory procedures such as licensing, state registration of medicines, quality control, and compliance with sanitary and hygienic requirements. This is established by the Law "On Medicines and Pharmaceutical Activity" and relevant presidential decrees [3,5,6].
- High quality and safety requirements. Because medicines directly affect human health, their production, storage, and sale are carried out on the basis of strict standards. In pharmacy activity, the requirements of "Good Pharmacy Practice (GPP)" are mandatory [5,6].
- Relatively high capital intensity. Establishing pharmaceutical activity requires special equipment, laboratory instruments, certification procedures, and qualified specialists. This leads to a higher volume of initial investment compared with other sectors [3].
- Innovative orientation. The sector develops based on the creation of new dosage forms, the introduction of technological innovations, and scientific research. Modernization of the pharmaceutical industry and development of innovative clusters are among the priority directions of state policy [5].
- Social significance. Pharmaceutical entrepreneurship performs not only the task of obtaining economic profit but also social functions such as providing the population with high-quality and safe medicines and producing import-substituting products [5,6].
- Specific nature of the market. Demand in the pharmaceutical market is stable, while price and assortment policy is often regulated by the state. These aspects distinguish the sector from other areas of trade [3].
- Need for qualified personnel. Pharmaceutical activity is carried out with the participation of pharmacists, pharmacists-technologists, and other specialists with special training. This requirement is established by legislation [3].

Development Factors of Small Business Activity in the Pharmaceutical Sector

Under the conditions of Uzbekistan, the development of small business activity in the pharmaceutical sector is determined by a number of economic, political, social, and scientific-technological factors. These factors include the following:

- State policy and strategic support. The pharmaceutical industry is recognized as one of the priority directions of the country's industrial policy. In recent years, a number of regulatory and legal documents have been adopted aimed at modernizing the sector, expanding local production, and attracting investment [5,6].
- Growth potential of the domestic market. The stability of domestic demand for pharmaceutical products and population growth in the republic contribute to market expansion. In recent years, increases in production volumes and expansion of export geography have shown the prospects of this direction [5].
- Development of science and innovation. Strengthening research activity in the pharmaceutical sector, introducing innovative developments into practice, and using modern production technologies are important components of state policy. In particular, special

attention is being paid to developing pharmaceutical clusters and forming innovative infrastructure [5].

- Qualified personnel and educational infrastructure. The sustainable development of the sector depends on the level of provision with qualified specialists. Necessary personnel are being trained through higher education institutions in pharmaceutical fields and the secondary specialized education system. This creates a labor-resource base for small business entities [3].
- Import substitution and localization policy. The significant share of imports in the pharmaceutical market creates a need to expand local production. State support for localization programs is creating new opportunities for small enterprises [5,6].
- Competitiveness and digital transformation. In market conditions, the introduction of modern management methods, innovative marketing, and digital technologies is important for increasing the competitiveness of small business entities. Digitalization processes are also being implemented gradually in the pharmaceutical sector [5].

Based on these features, it can be stated that the current growth of small business activity in the pharmaceutical sector is connected with the increasing number of enterprises producing phytopreparations, biologically active supplements, and other products used in traditional medicine.

As of April 2026, the regional indicators of small business entities in the pharmaceutical sector of Uzbekistan are as follows:

Tashkent city is the absolute leader in the sector, with 3,100 entities, maintaining the highest concentration. It is followed by Samarkand with 1,650 entities, Fergana with 1,500 entities, and Kashkadarya region with 1,350 entities, all showing high growth rates.

In the Fergana Valley, Andijan region has 1,200 entities and Namangan region has 1,150 entities, showing high density and a strong inclination toward production. Tashkent region has 1,100 entities due to its logistical advantages, while Bukhara has 950 entities and is distinguished by its tourism potential.

Activity is also increasing in other regions of the republic: Surkhandarya has 880 entities, Khorezm has 720 entities, and Karakalpakstan has 650 entities. Jizzakh has 550 entities, Navoi has 480 entities, and Syrdarya has 420 entities, where intensive growth is being observed due to free economic zones and industrialization.

Several factors may explain the increase in such enterprises. First, the production of such products does not require large and complex technologies. Second, due to public trust in these products, market demand for them is high. Third, they are obtained from natural sources, and such raw materials are abundant in our country.

The problems hindering the activities of small business entities in the pharmaceutical sector, especially small production enterprises and private pharmacies, can be divided into several main groups. From the perspective of 2026 market requirements and changes in legislation, these obstacles are as follows:

1. Financial Difficulties in Transitioning to International Standards

At present, GMP (Good Manufacturing Practice) standards for all medicine manufacturers and GPP (Good Pharmacy Practice) standards for pharmacies are being made mandatory.

Problem: For small entrepreneurs, obtaining these certificates requires major expenses for modernizing premises, purchasing expensive laboratory equipment, and training employees. Many small enterprises do not have sufficient working capital for such investments.

2. Dependence on Imported Raw Materials and Substances

Most medicines produced in Uzbekistan are prepared on the basis of imported raw materials or substances.

Problem: Rising logistics costs and exchange-rate fluctuations directly affect the cost of finished products. Since small enterprises cannot purchase raw materials in large quantities at wholesale prices like large factories, their products may lose competitiveness in the market.

3. Complexity of Registration and Licensing

The process of state registration of medicines requires a long time and complex laboratory tests.

Problem: The time required to bring a new product to the market, sometimes from six months to one year, may interrupt the financial flow of a small entrepreneur. Frequent changes in licensing requirements also create difficulties for small businesses in adapting.

4. Market Consolidation

The share of large pharmacy chains and major holdings is increasing in the pharmaceutical market.

Problem: It is difficult for small individual pharmacies to compete with large chains in terms of price. Large chains obtain goods directly from factories and with large discounts, which reduces the profitability of small pharmacies.

5. Shortage of Qualified Personnel

There is a shortage of specialists in modern pharmaceutical technologies, pharmacovigilance, and quality management.

Problem: Strong specialists usually move to large foreign companies or major local factories that offer higher salaries. It is becoming difficult for small businesses to retain qualified personnel.

6. Digitalization and Marking Requirements

The system of mandatory digital marking of medicines (“Asl Belgisi”) has been introduced.

Problem: Installing marking equipment and working with special software creates an additional administrative and technical burden for small business entities.

To solve these problems, the state is taking measures to allocate preferential loans to small entrepreneurs, simplify the process of registering medicines, and create infrastructure for small manufacturers within the framework of “pharmaceutical clusters.”

Conclusion and Recommendations

The results of this study show that small business activity in the pharmaceutical sector is developing as an important component of Uzbekistan’s economy. In recent years, the legal, organizational, and financial support mechanisms created by the state have provided favorable conditions for small business entities to enter the sector and expand their activities.

The analysis showed that the following factors directly affect the development of small business in the pharmaceutical sector: state policy and strategic support, the growth potential of the domestic market, the formation of scientific and innovative infrastructure, the system of training qualified personnel, import-substitution policy, and digital transformation processes. At the same time, there are also certain problems in the sector, including high technological production costs, dependence on imported raw materials and substances, limited financial resources for small enterprises, and difficulties in fully implementing quality management systems.

Based on the above conclusions, it is appropriate to make the following recommendations:

1. Further expand tax incentives and credit-support mechanisms for small business entities in the pharmaceutical sector.
2. Reduce import dependence by developing the local raw-material base and establishing the production of pharmaceutical substances.
3. Strengthen cooperation between research institutions and manufacturers and simplify the commercialization process of innovative projects.
4. Provide methodological and financial support for the gradual introduction of international quality standards, such as GMP, GDP, and others, in small pharmaceutical enterprises.
5. Increase production efficiency and transparency through the widespread introduction of digital management systems.

Supporting small business activity in the pharmaceutical sector is of great importance for ensuring Uzbekistan's pharmaceutical independence, supplying the domestic market with high-quality medicines, and increasing export potential.

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STRATEGIES OF A LEADER AND EMPLOYEES IN ORGANISATIONAL DEVELOPMENT AND THEIR OUTCOMES: A GAME APPROACH

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Abstract. *Facing change interventions members of organization may behave in a different way depending on their individual economic incentives or trade-offs to be received participating in a change process and, as a result of it, projected growth of productivity or change objectives may not be met in full capacity. This happens when corporate management and employees do not cooperate in change process or no consensus is met between management and employees during the change implementation. The aim of this paper is to examine with the game theory approach the economic nature of behavioral transactions in change process in order to demonstrate the benefit of a mutual cooperation or consensus that all change participants have balanced their interests to achieve their change objectives.*

Keywords: *game theory, change management, organizational development, mathematical modelling.*

Introduction

The contemporary environment of unpredictable uncertainty surrounding organisations sets multifarious criteria for organisational development practitioners. The external factors are interrelated and changing rapidly, making the environment for all kinds of organizations highly uncertain and chaotic (Peters, 1987). Within such complex environment the organisational development – change became a continuous process that determines organizational life today. Management guru Peter Drucker advised that the choice of a change is a systematic and purposeful abandonment of organization's theory of the business or be over taken over by events. Prior to the decision on which strategic change to implement in an organization, one needs to ***know how to implement change***! (Drucker, 1994)

Outcome of any business process is measured economically so is a change process. Overall economic performance of change depends on transaction costs of organizational members, and these primarily mirror the level of trust in an organization – between corporate management and employees. The level of trust is predetermined by organizational culture. An effective organizational culture has a strong moral content. Morality tends to resolve complex change problems that formal procedures cannot. A strong organizational culture, therefore, helps to overcome change resistance, consequently reduces change transaction costs and improves overall organizational performance. Thus the organizational success depends on the quality of its culture.

The aim of this paper is to examine the transactions between the change agent, usually a corporate leader or the leader, and organization members, employees or the followers, and the outcomes of their economic activity, especially, when a mutual consensus is met within a certain set of change parameters – motivations/incentives, level of the leader's manipulation and other organization's cultural parameters.

The Conceptualization - Change Management as a Game

The people in an organization, i.e. management (leader(s)) and employees (followers), plan and implement organizational change. The success of a change process depends on the management of relationships between the change leader and the followers, and what kind of behavioral climate is established in an organization. Irrelevant settings of a change climate may lead to a failure of any superiorly designed change intervention process as the change agents may ignore change needs and the resistance to change of the organizational members – the employees as well as the managers. Therefore, a thorough understanding of transactional economics between parties involved in process, anticipating possible problems of the change management and establishing the most cooperative climate are principal factors of a change intervention success.

Planned change process can be considered as the game where two parties are involved – the leader establishes new rules and motivations to accept these rules, the followers evaluate these rules and incentives and, consequently, prefer a certain behavioral strategy – to reciprocate, cheat/slack or avoid. We assume that participating in a change game, both parties are governed by economic considerations, and they exchange material and emotional values as a result of a certain behavioral preference. In this context, a primary objective of the leader is to achieve the highest economic benefit implementing a change.

Implementing a change, the leader has a dilemma to motivate the followers spending on their monetary and non-monetary incentives and increase the net growth of organizational productivity. How to establish an organizational equilibrium or win-win situation?

A successful altruistic leader weighs up an organization's benefits and the followers pay-offs from change implementation in order to make everyone 'satisfied' with change outcomes or, in game theory expressions, establish an organizational equilibrium by the means of optimum consensus. The leader establishes certain new work norms and also certain incentives to motivate the followers to cooperate in this game honestly accepting new work requirements. Some followers tend to overestimate their own performance level, and accordingly overprice own cost of effort. Thus, some followers in organization may find established change incentives undervalued, and behave as 'free-riders' demonstrating solidarity but providing no effort, even cheating to gain some extra incentives. The 'free-riders' problem creates certain problems for followers' voluntary cooperation (Collard, 1981). As followers may have their an estimated cost of their own effort and hope for a certain level of incentives, their decision whether or not to cooperate depends on exposed level of incentives or pay-offs. A simplified game of cooperation in change process can be modeled with well-known 'prisoner's dilemma' (Rasmusen, 2001) with two available strategies – confess and not confess or, in our case, cooperate and not cooperate.

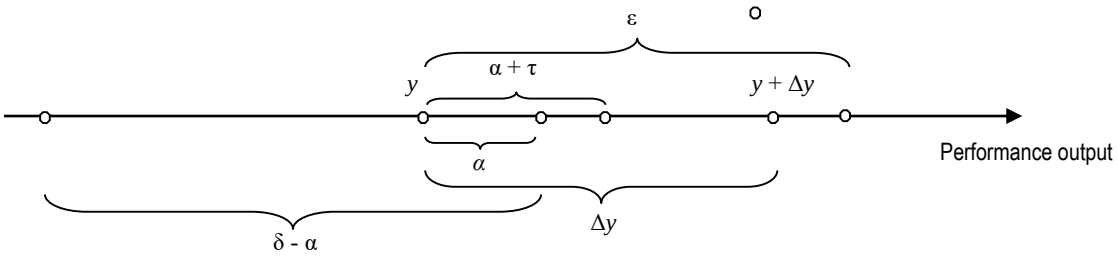
A similar but related mostly to case of a trade was elaborated by Mark Casson (Casson, 1991). We will use this approach with some changes to describe the organizational change. We assume that a change costs at the amount of $C > 0$. The change cost may consist of expenses for diagnosing an organization, planning and implementation of the change intervention, i.e. all possible cost borne to implement a change. Implementing a successful change, the leader expects to gain a growth in organizational output, $\Delta y > 0$. As any planned change, this change implementation also requires the organization members - followers, making an extra effort with the perceived cost of $\varepsilon > 0$. The cost of this effort as a rule, exceeds projected growth $\varepsilon > \Delta y$.

To encourage the followers the leader establishes additional motivation consisting of monetary incentives - α, and non-monetary/intrinsic incentives with the perceived cost of - τ, such as promotions, empowerment, recognitions, improved quality of the work life etc. Obviously, $\alpha + \tau > 0$. Nevertheless negative aspects also exist - diagnosis of an organization reveals the fact that

corporate disobedience rate, $0 \leq \chi \leq 1$, is associated with incentives to cheat, $\beta > 0$, and the case of mutual cheating may reduce incentives of the followers to the amount of δ which is usually more than legally offered monetary incentives, i.e. $\delta - \alpha > 0$.

In this context, parameters of this game can be illustrated as in the following Figure 1. However it must be noted that these parameters may have a various relationship different than the illustrated ones.

Figure 1. The disposition of parameters in the change implementation game.



The followers honest cooperating in change process may gain an additional incentive paying an effort with a certain perceived cost if the leader cooperates honestly in the change. The followers they get only material incentive whilst paying an effort and lose the amount of cheating because of the leader's cheat/dishonest cooperation, i.e. the leader is reluctant to motivate the followers morally. When the followers cooperate in change honestly, a cooperative leader acquires performance growth, the followers' effort and moral satisfaction and pays material incentives for these gains to motivate the followers for further cooperation. If the followers are honest, a non-cooperative leader, who is inactive in the game or, more precisely, does not transfer planned incentives to the followers, also achieves only a growth of performance. Furthermore, such leader gains additional incentives to cheat since the leader is not over-performing whilst the followers do.

Some followers may prefer the status of 'free-riders' gaining both material reward for participation, and additional incentive for cheating the cooperative/honest leader - such behavior can be derived from a behavioral character of the followers - a lower sense of quilt, σ ($0 \leq \sigma \leq 1$). If the cooperative leader is cheated an expected organizational outcome is reduced at the amount of cheat incentive plus material incentives paid for the followers.

Cheating a non-cooperative leader, the followers do not acquire a moral discomfort but material loss. In this case, a non-cooperative leader will also lose the amount, presumably exceeding expected growth, but retains material incentives not rewarding the followers' dishonesty.

Voluntary participation in a change process was a precondition of our game situation, i.e. there is no strict legal enforcement for honest cooperation. If the followers decide not to be involved in the change implementation game they receive a zero pay-off or quit the organization and, consequently, the organizational performance growth is not met. In this situation, a cooperative leader loses the cost of the followers' effort while such non-cooperation does not involve such real economic cost.

Individual perceptions of the followers within organization are not homogeneous or their behavior is not perfect collectivistic that they all without exception may not follow a common strategy. To determine the probability of a choice, game theorists deploy so called 'perceived probability' or 'assigned value' coefficients for estimating the probability of a certain strategy choice. In our case, it would be more appropriate to link such probability of choice to the

organization's disobedience rate, $0 \le \chi \le 1$, or as other authors use as a crime rate. It belongs to an individual follower as well as a group of followers. In the former case, disobedience rate can be considered as an approximated probability of randomly sampled individual's choice of dishonesty or, in the latter case, as an estimated part of the group members tend to disobey.

It should be noted that in all situations except mutual cheating the leader, despite of his behavior, bears an initial cost of change development. In the light of these discussions, pay-offs matrix of the change implementation game can be obtained as illustrated in Table 1.

Table 1. Change implementation game pay-offs matrix.*

		Leader	
	Strategy	**Cooperative**	**Not cooperative**
Followers	**Honest cooperation**	$\alpha + \tau - \varepsilon$; $\Delta y + \tau + \varepsilon - \alpha - C$	$\alpha - \varepsilon - \beta$; $\Delta y - \alpha + \beta - \gamma - C$
	Dishonest cooperation	$\alpha + \beta - \gamma$; $\Delta y - \alpha - \beta - C$	$\alpha - \delta$; $\Delta y + \alpha - \delta$
	Non-cooperation / Avoidance	0; $-C - \varepsilon$	0; $-C$
Perceived probability of the leader's strategy		$1 - \chi$	χ

* Pay-offs (Followers; Leader)

To convert this game from 'prisoner's dilemma' to 'assurance' game the leader has to understand game outcomes, and to manage the inputs. To do this 'the change process game' has to be analyzed from the viewpoint of the followers.

From economic considerations if an overall reward for honest cooperation of the followers is higher than possible incentive for cheating, $\alpha + \tau - \varepsilon > \beta$, the followers preferred strategies can be determined from the following inequality:

$$(1-\chi)(\alpha + \beta - \gamma) > (1-\chi)(\alpha + \tau - \varepsilon) > 0 > \chi(\alpha - \delta) > \chi(\alpha - \varepsilon - \beta) \quad (1)$$

or

'free-rider' while the leader is honest > ***mutual honest cooperation*** > ***mutual non-cooperation*** > ***mutual cheating*** > ***simpleton***

The above inequality (1) states that if the reward exceeds the cheating incentive, all followers would cooperate in the game honestly or cheat if the leader is cooperative/honest, otherwise the game can stick in a mutual avoidance as the followers, having economic considerations, do not prefer a mutual cheating or being simpletons. However, on the other hand, perceived probability of the leader's honesty or say trust in the leader's honesty and the guilt factor of individuals may dramatically change preferred strategies of the followers. High trust in the leader may stimulate the followers' honest cooperation even if the leader decides not to cooperate. This is usually true in the first move and the trust may change if the game is repeated with the leader's same strategy.

Thus the game or, in this case, the change intervention outcome is positive if

$$\begin{cases} \gamma \ge E - \Delta y; & (2) \\ \Delta y \ge E. & (3) \end{cases}$$

Referring to (3) it is can be stated that

- an honest cooperation is preferred instead of non-cooperation if $\chi \le \frac{(\alpha + \tau - \varepsilon)}{(\tau + \beta)}$; (4)
- a non-cooperation is preferred instead of cheating if the guilt factor is

$$\gamma \ge \beta + \delta + \frac{(\alpha - \delta)}{(1 - \chi)}; \quad (5)$$

It must be noted that an honest cooperation is chosen instead of cheating if the guilt factor improved to

$$\gamma \ge \delta - \tau + \frac{(\delta - \beta - \varepsilon)}{(1 - \chi)}.$$

Let assume that the altruistic leader increasing intensity of manipulations wants to minimize disobedience rate, i.e. improve the followers' morale, and as a result to maximize the expected growth rate. The leader's extensive manipulations may positively influence the moral climate of an organization reducing disobedience rate of the followers and, consequently, the number of followers deciding to slack lessens, and the organization's performance growth approximates a projected level of output. The leader's objective function for this case will be to increase the growth reducing disobedience rate, i.e.

$\omega_1 = \Delta y\,(1 - \chi) - C.$ (6)

Optimal Strategy of the Altruistic Leader in Organizational Development: Organizational Equilibrium through Mutual Consensus

The previous part considered change implementation game from the standpoint of the followers, i.e. employees needing to change their work attitudes accepting new norms. It would be a naïve way of gaming if the organization management - the leader, on one side, and employees - the followers, on the other side, were guided by their own objectives expecting the maximum incentive. However it may happen that the owner(s) of the company but not an employed manager and employees have their own expectations concerning change outcomes and both are reluctant to understand each other's objectives.

Unlike it, an altruistic leader is recommended to maximize the amount of trade incentives improving the followers' morale in order to encourage them in a fair trade. In this case, an altruistic game leader expects the reciprocity of a trade partner offering more incentives [Casson, 1991]. However the change process is a different game in which an organizational equilibrium is more important.

Also the leader adopting utilitarianism may try to achieve the growth of the both parties' incentives as well as the followers' effort and a better moral climate in the organization. Therefore, there is an economic rationale for the leader to develop the organizational change objectives reducing expected incentives of the owner(s) and the followers to a common denominator. The leader maximizes common incentive settings with a condition that honest cooperation is economically attractive than cheating. In this case, the objective function is

Organizational Equilibrium Gain = $\boldsymbol{max}_{\mu \to \infty}$(*Leader's incentives + Followers' incentives*), where μ - the leader's manipulation intensity or cost of the leader's manipulations.

In the case of the organizational equilibrium, the leader's objective function will be

$$\varpi_e = 2\tau + \varepsilon - \Delta y - \frac{\varepsilon - \Delta y}{\mu}\left[3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C\right], \quad (7)$$

or

$$\varpi_e = 2\tau + \varepsilon - \Delta y - \chi_e\left[3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C\right]. \quad (7a)$$

Here we have to note that manipulating the followers the leader does not produce but contrarily consumes financial resources delivering manipulations. In general, such kind of expenses can be projected as the following linear function

$$\xi = \xi_f + \xi_v \mu \quad \mu > 0, \quad (8)$$

and if μ=0 then ξ=0, where ξ_f – fixed cost of manipulations (say fixed cost of the leader's remuneration), and ξ_v – variable cost of manipulations per period of time (say cost of activities associated with the leader's manipulations).

In this case, the utility function for the case of an organizational equilibrium is

$$\upsilon_e = \varpi_e - \xi. \quad (9)$$

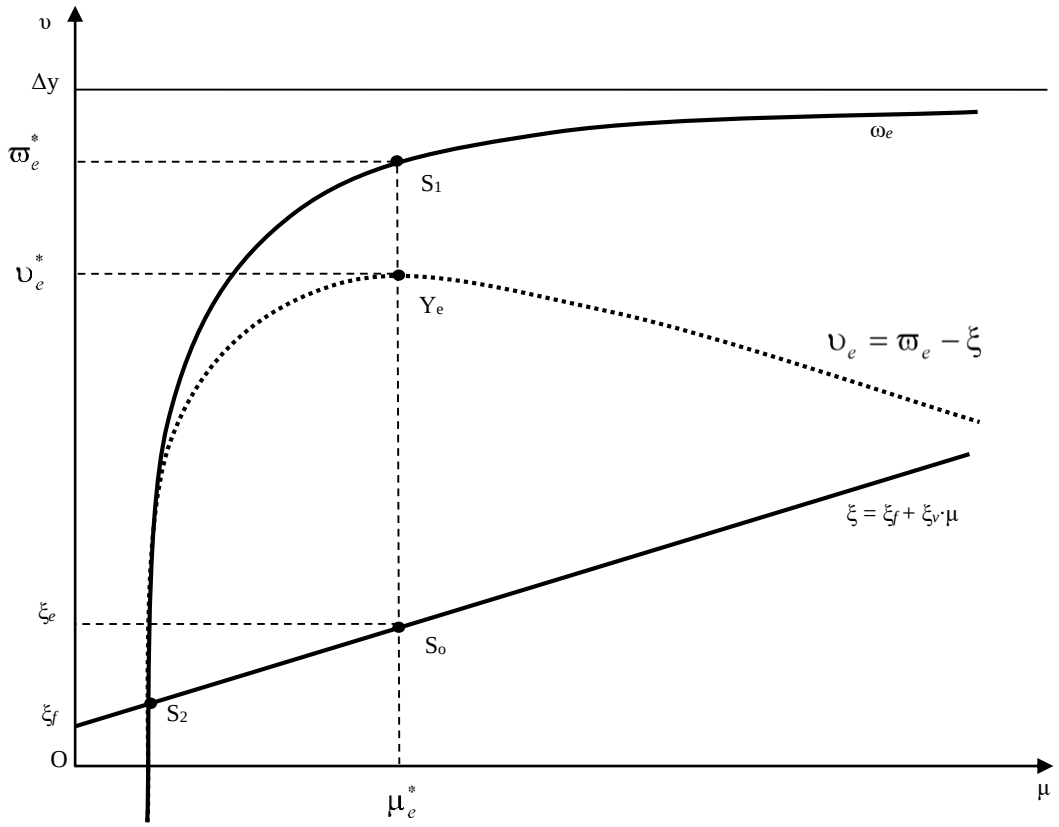
Considering (7), the formulas (8) and (9) can be re-written as

$$\upsilon_e = 2\tau + \varepsilon - \Delta y - \frac{\varepsilon - \Delta y}{\mu}\left[3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C\right] - \xi_f - \xi_v \mu, \quad (10)$$

whereas ε – Δy >0, and $\delta \geq \alpha + \tau \geq \beta \geq \varepsilon \geq \Delta y \geq \alpha \geq \tau \geq 0$.

Following a simple mathematical technique, i.e. equaling the first derivative of (10) to zero, the optimal point of the leader's manipulation can be obtained, see the Figure 2.

Figure 2. Optimal manipulation under an organizational equilibrium of the altruistic leader.



The negative value of the second derivative of (10) proves that υ_e^* is global optimum of the organizational equilibrium in the given space, $\mu \geq 0$.

Maximization of the utility function (7) in behavioral zero-sum game between the leader and the followers can be considered as a duopoly welfare game model with a Stakelberg leader and a Cournot follower (Rasmusen, 2001) - the leader moves first and commits first gaining some

net value whilst the followers with continuous strategy space are not involved in cooperative game as they are not aware of the leader's utility function and strategy pay-offs; however they are inclined towards establishing Pareto optimality perceiving the best response function in terms of disobedience rate

$$\chi = \begin{cases} 1 & E - \Delta y > \mu \geq 0 \\ (E - \Delta y)/\mu & \mu \geq E - \Delta y > 0. \end{cases} \quad (11)$$

Based on (11), (7a), (8), and (10) the following state parameters of the optimal organizational equilibrium for the game can be found:

$$\mu_e^* = \left[\frac{(\varepsilon - \Delta y)[3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C]}{\xi_v} \right]^{1/2}; \quad (12)$$

$$\chi_e^* = \left[\frac{(\varepsilon - \Delta y) \cdot \xi_v}{3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C} \right]^{1/2}; \quad (13)$$

$$\varpi_e^* = 2\tau + \varepsilon - \Delta y - \{(\varepsilon - \Delta y)[3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C] \cdot \xi_v\}^{1/2}; \quad (14)$$

$$\upsilon_e^* = 2\tau + \varepsilon - \Delta y - 2 \cdot \{(\varepsilon - \Delta y)[3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C] \cdot \xi_v\}^{1/2} - \xi_f. \quad (15)$$

What is a real gain of having the organizational equilibrium in a change process?

In a normal case, i.e. no organizational equilibrium is sought, taking into account (6), (8), (9) and (11), utility function of the altruistic 'narrow materialistic' leader's objective function can be as

$$\upsilon_1 = \Delta y \left[1 - \frac{E - \Delta y}{\mu} \right] - C - \xi_f - \xi_v \mu. \quad (16)$$

Equaling the first derivative of the utility function in manipulation space to zero, $d\upsilon_1/d\mu = 0$, the parameters of the maximum utility value (μ^*, χ^*, ϖ_1^* and υ_1^*) for the normal case can be obtained.

It is interesting to learn that the best compromise between an organization and its employees is met if the organizational equilibrium is established. It is somehow acceptable if the organizational effort, *E*, is equal to the followers effort, ε, (E = ε). Then a difference of the values (μ^*, χ^*, ϖ_1^* and υ_1^*) and (12-15) accordingly will give us a value of the perceived cost of a compromise of the narrowly materialistic leader in case of the organizational equilibrium. So the cost of the concession is seen in the following expressions:

$$\Delta\mu_e^* = \mu_1^* - \mu_e^* = \frac{\varepsilon - \Delta y}{\xi_v} \cdot \left\{ \Delta y^{1/2} - [(\varepsilon - \Delta y)[3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C]]^{1/2} \right\} < 0; \quad (17)$$

$$\Delta\chi_e^* = \chi_1^* - \chi_e^* = \sqrt{(\varepsilon - \Delta y) \cdot \xi_v} \cdot \left\{ \Delta y^{-1/2} - [3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C]^{-1/2} \right\} > 0; \quad (18)$$

$$\Delta\varpi_e^* = \varpi_1^* - \varpi_e^* = \Delta y - (\varepsilon - \Delta y) - 2\tau - C - \\ - \sqrt{(\varepsilon - \Delta y) \cdot \xi_v} \cdot \left\{ [3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C]^{1/2} - \Delta y^{1/2} \right\}; \quad (19)$$

$$\Delta\upsilon_e^* = \upsilon_1^* - \upsilon_e^* = \Delta y - (\varepsilon - \Delta y) - 2\tau - C - \\ - 2\sqrt{(\varepsilon - \Delta y) \cdot \xi_v} \cdot \left\{ [3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C]^{1/2} - \Delta y^{1/2} \right\} < 0. \quad (20)$$

It is seen that

$$\Delta y < (\varepsilon - \Delta y) + 2\tau + C + 2\sqrt{(\varepsilon - \Delta y) \cdot \xi_v} \cdot \left\{ [3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C]^{1/2} - \Delta y^{1/2} \right\},$$

whereas $\Delta y < \left[3\varepsilon + 2(\alpha + \tau) - 2(\Delta y + \delta) + C\right]$.

Thus the negative value of (20) proves the idea that the organizational equilibrium, once the management and employees' expectations are optimized or balanced, brings higher growth of an organizational performance. Thus, the cooperation of parties increases the net organizational performance growth.

On the other hand, the negative value of (17) means that the organizational equilibrium requires a higher intensity of manipulations from the leader that leads to the evidence of (18), i.e. a clear demonstration of the reduced followers' disobedience rate. Even though it is difficult to judge about gains or losses of the leader's objective function (19), we can assume that an increased intensity of the leader's manipulations obviously increases the leader's consumption, hence the gain in the utility is incurred due to a better moral of the followers.

Particularly, such results reveal again the advantage of mutual altruistic cooperation over an egoistic behavior or mutual competition.

Conclusion

The game simulation to research the organizational change process and predict its outcomes in the case of mutual consensus between the leader and followers proved that proactive leadership with maintaining the trust in organization through appropriate reward management can achieve higher than planned net growth in organization due to the improved followers' culture. Clear communication of the change objectives and fulfillment of commitments by the leader during the organizational development process improve the employees' moral and level of their reciprocal honest cooperation minimizing the resistance to change.

Given formulas can be used to forecast to a certain extent the economic and behavioral outcomes of a planned change though as the next stage of research it is advised to organize a game simulation with a group of participants in order to test the suitability of the behavioral assumptions made in the article.

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FEATURES OF ENTERING ENTREPRENEURIAL ACTIVITY IN THE PHARMACEUTICAL SECTOR

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https://doi.org/10.5281/zenodo.20068036

Abstract. *This scientific article, taking into account that the pharmaceutical sector is a highly regulated, socially significant and capital-intensive type of economic activity, provides an in-depth analysis of the theoretical foundations of the initial organization of entrepreneurial activity in this field, as well as its legal, economic and organizational features within the framework of the current legislation of the Republic of Uzbekistan. The article also puts forward scientifically grounded conclusions and recommendations for improving entrepreneurship policy in the pharmaceutical sector.*

Keywords: *pharmacist, pharmaceutical economics, entrepreneurship, license, state registration, investment, risk management, pharmaceutical market.*

Introduction

Pharmaceuticals is one of the strategically important branches of the healthcare system. In the Republic of Uzbekistan, the development of the pharmaceutical sector is one of the priority directions of state policy. Unlike general business, starting entrepreneurial activity in this field requires fulfilling complex legal, economic and technological requirements. According to the World Health Organization, in many countries expenditures on medicines account for 20-30 percent of total healthcare expenditures [1].

In the Republic of Uzbekistan, developing and establishing entrepreneurship in the pharmaceutical sector is considered one of the priority directions of state policy. At the same time, dependence on imports and fluctuations in exchange rates have a negative impact on price stability in the pharmaceutical market [2].

The main purpose of the study is to examine the mechanisms currently operating in the field of pharmaceutical entrepreneurship in Uzbekistan, to conduct a comparative analysis with international experience, and to develop scientifically grounded conclusions for improving policy in this area.

Literature Review and Theoretical Foundations

Legal foundations of pharmaceutical activity in Uzbekistan. Pharmaceutical activity is regulated on the basis of the following regulatory and legal documents:

- the Law "On Medicines and Pharmaceutical Activity" [3];
- the Law "On Guarantees of Freedom of Entrepreneurial Activity" [4];
- the Law "On Licensing, Permitting and Notification Procedures" [5];
- relevant resolutions of the Cabinet of Ministers [6].

Main Part

Licensing and State Registration

In order to ensure proper control over the activities of entrepreneurial entities in the pharmaceutical market of the Republic of Uzbekistan, a licensing system has been established.

Pharmaceutical production, wholesale trade and retail trade are carried out on the basis of a license. Medicines are subject to mandatory state registration, and their quality, safety and effectiveness are assessed on the basis of scientific expertise.

Licensing is one of the forms of state regulation and control over the implementation of pharmaceutical activity. The main purpose of licensing is to protect the lawful interests of citizens and state security. In the circulation of medicines, licensing is carried out in order to ensure the quality, effectiveness and safety of medical care, as well as to prevent entrepreneurial entities that do not meet the required standards from entering the pharmaceutical market [5].

In the Republic of Uzbekistan, licensing of pharmaceutical activity, including the production and preparation of medicines and the wholesale and retail sale of medicines and medical devices, is carried out in accordance with the procedure established by Resolution No. 80 of the Cabinet of Ministers of the Republic of Uzbekistan dated February 21, 2022 [6].

According to this procedure, an application for obtaining a license is submitted electronically through the website license.gov.uz or through the Single Interactive State Services Portal of the Republic of Uzbekistan, with selection of the licensed type of activity, including each of its subtypes.

GMP and Quality Management Requirements

The content of Good Manufacturing Practice (GMP) requirements in pharmacy, their legal foundations and their role in the quality control system are analyzed. GMP requirements are a set of comprehensive norms aimed at ensuring quality and effectiveness in the process of medicine production. On the basis of production processes developed by the World Health Organization (WHO) [7], the United States Food and Drug Administration (FDA), and the International Council for Harmonisation (ICH), the main principles of GMP include quality management, validation, documentation, cleaning qualification and control over the production environment. GMP requirements provide for control over all stages of the production process, including:

- control of raw materials;
- process validation;
- documentation;
- sanitary and hygienic rules [7].

Economic and Investment Features

The pharmaceutical business is considered a highly capital-intensive sector. It is a highly regulated, socially significant and capital-intensive type of economic activity. The cost structure includes research and development, laboratory equipment, clinical trials and marketing expenses. Pharmaceuticals is a sector with high capital intensity, where the main part of expenditures consists of research and development (R&D), laboratory equipment, clinical trials and marketing. The creation and production of new medicines is a long-term, risky and expensive process, and entrepreneurial activity in this field plays an important role in creating innovative products and developing the healthcare system. These include:

- High costs: special laboratories and clinics are required for research and experiments.
- Innovation and marketing: the production of a new medicine and its promotion in the market require large financial investments.
- Risk: the long duration of clinical trials and the lack of guaranteed success lead to high costs [8].

Marketing and Competitive Environment

Pharmaceutical marketing relies on close cooperation with physicians, scientific seminars, pharmacovigilance (drug safety monitoring) and brand reliability in a competitive market. The main objective is to strengthen market share by proving the clinical effectiveness of medicines, complying with international standards and increasing trust [7].

Innovative Development

Digital labeling, electronic monitoring systems and biotechnological innovations are the main directions of modern pharmaceutical development.

Results and Discussion

The comparative analyses conducted show that entry into entrepreneurship in the pharmaceutical sector in Uzbekistan is aimed at ensuring long-term and sustainable development. The control mechanisms introduced by the state improve social protection of the population and the activities of entrepreneurs. At the same time, they create a foundation for ensuring innovative development in the long term.

International experience shows that the gradual introduction of HTA and value-based pricing mechanisms increases the efficiency of the healthcare system and contributes to the rational management of budget expenditures. These approaches can also be adapted and applied in the conditions of Uzbekistan [9].

Conclusion and Recommendations

The results of this scientific study show that organizing entrepreneurial activity in the pharmaceutical sector is a complex, multi-stage and highly regulated process that has not only economic but also social significance. In the Republic of Uzbekistan, the legal framework for pharmaceutical activity has been formed, and the quality, safety and effectiveness of medicines are ensured through licensing, state registration and GMP requirements.

During the study, it was determined that although national regulatory mechanisms are mainly aimed at protecting public health, they need further improvement from the point of view of increasing innovative development and investment attractiveness. International experience, in particular the standards developed by the World Health Organization (WHO), the United States Food and Drug Administration (FDA), and the International Council for Harmonisation (ICH), demonstrates an effective model of quality management and risk management in the pharmaceutical sector.

In addition, reducing dependence on imports in the pharmaceutical market of Uzbekistan, expanding domestic production, supporting research activities and introducing digital control systems should be defined as priority tasks.

The development of entrepreneurship in the pharmaceutical sector requires a comprehensive approach by the state, integration with international standards, and management mechanisms based on the principles of an innovative economy. Indeed, systematic reforms in this direction will serve, in the long term, to strengthen the stability of the healthcare system, increase the competitiveness of the national economy, and improve public health.

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THE ROLE AND SIGNIFICANCE OF CREATIVITY IN CREATING A COMPETITIVE BRAND

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https://doi.org/10.5281/zenodo.20067161

Abstract*. This article analyzes the role and strategic significance of creativity in creating a competitive brand. In modern market conditions, competition increasingly occurs not only between products but also between meanings, values, and consumer experiences. Creativity helps brands distinguish themselves visually and conceptually, establish emotional connections with consumers, and create differential advantage. The article examines key elements such as brand identity, storytelling, innovative creativity, symbolic superiority, emotional influence, and brand equity. It argues that creative strategies transform a brand from a simple trademark into a meaningful social and psychological phenomenon. Through examples such as Nike, Apple, Tesla, Dyson, and LEGO, the study shows how creativity strengthens recognition, loyalty, consumer trust, and long-term competitiveness. The article concludes that sustainable brand equity can be achieved only when creativity is consistently integrated into all stages of brand strategy, communication, design, innovation, and consumer engagement.*

Keywords: *creativity, brand, competitiveness, brand identity, storytelling, brand equity, differential advantage.*

Introduction

In the modern market space, competition no longer takes place between products, but between meanings. Consumer choice is based not only on functional indicators, but also on the identity, values, and emotional experience associated with the brand [Aaker, D. A. (1991). *Managing Brand Equity: Capitalizing on the Value of a Brand Name*. New York: Free Press, pp. 7–15]. Therefore, the issue of creating a competitive brand has become a complex process that is broader than the technical aspects of marketing strategy and is closely connected with social, cultural, and psychological factors. In such conditions, creativity appears not as a simple decoration or advertising method, but as a strategic resource that forms differential advantage [Keller, K. L. (2013). *Strategic Brand Management: Building, Measuring, and Managing Brand Equity*. 4th ed. Pearson Education, pp. 57–63].

In an era when the flow of information has sharply increased and communication channels have multiplied, gaining consumer attention is becoming increasingly difficult. Studies show that an average person encounters more than 4,000 advertising messages during the day, but only a very small part of them remains in memory [Kotler, P., & Keller, K. L. (2012). *Marketing Management*. 14th ed. Pearson Prentice Hall, pp. 241–250]. Therefore, attracting attention and being memorable are no longer just qualities, but advantages determined by a creative approach.

In scientific literature, brand competitiveness is often explained through the concepts of brand equity, consumer loyalty, and differential positioning [Holt, D. (2004). *How Brands Become Icons: The Principles of Cultural Branding*. Harvard Business School Press, pp. 3–12]. However, the role of creativity as a mechanism for the formation of these elements has not been sufficiently

analyzed in a comprehensive manner. Nevertheless, unique communication, original content, and emotional storytelling created through creative strategies elevate a brand not only to the level of something visible, but also to the level of a phenomenon that can be felt [Ries, A., & Trout, J. (2001). *Positioning: The Battle for Your Mind*. McGraw-Hill, pp. 19–24]. As a result, a brand becomes not merely a trademark, but a means of spiritual and social identification.

The purpose of this article is to systematically analyze the mechanisms through which creativity influences brand competitiveness, to identify its main elements, and to develop practical recommendations.

Materials and Methods

This article is based on theoretical and analytical study of scholarly literature on branding, creativity, brand identity, storytelling, brand equity, differential positioning, and consumer behavior. The study uses descriptive analysis, comparative analysis, and conceptual analysis to examine the role of creativity in creating a competitive brand. The main sources include works by Aaker, Keller, Holt, Kapferer, Kotler and Keller, Kim and Mauborgne, Morin, Ries and Trout, as well as Uzbek-language sources on branding and marketing strategy.

Results

1. Brand Identity and the Role of Creativity

Brand identity is the main means that distinguishes a competitive brand in the market. It is a system that unites the visual, conceptual, and emotional characteristics of a brand [Aaker, D. A. (1996). *Building Strong Brands*. New York: Free Press, pp. 95–108]. Creativity plays an important role in making this system not only attractive, but also memorable and strategically effective.

The creative elements of brand identity include the following:

Name and slogan: creating a memorable name and slogan that reflect the meaning of the brand. For example, Nike’s “Just Do It” is a universal message that expresses action and willpower.

Logo and visual design: ensuring the uniqueness and recognizability of a brand through a color palette, typography, and graphic elements.

Packaging and product design: creating aesthetically attractive solutions that enhance the consumer experience.

Creative visual identity shapes the consumer’s first impression and helps the brand be recognized quickly. Apple’s minimalist design is a clear example of this: the consumer buys from this brand not only a phone, but simplicity and an innovative experience [Keller, K. L. (2013). *Strategic Brand Management*. Pearson Education, pp. 147–155].

2. Communication and Storytelling Strategy

Another key factor that distinguishes a brand from its competitors is its communication strategy and storytelling. According to D. Holt’s research, iconic brands do not merely sell products; they create cultural mythology [Holt, D. (2004). *How Brands Become Icons*. Harvard Business School Press, pp. 35–46]. This approach includes the following elements:

Emotional connection: creating an emotional experience in the consumer through content and campaigns.

Interactivity: encouraging consumer participation through social networks and digital platforms.

Narrative approach: conveying the values, history, and goals of the brand in the form of a story.

This approach turns the brand not only into a visible phenomenon, but also into one that can be felt. Tesla is a vivid example of this: the consumer buys not a car, but an investment in the future [Kapferer, J.-N. (2008). *The New Strategic Brand Management: Creating and Sustaining Brand Equity Long Term*. 4th ed. London: Kogan Page, pp. 171–179].

3. Innovative Creativity and Differential Advantage

Innovative creativity directs a brand toward new thinking and the creation of unique solutions. According to Kim and Mauborgne's concept of the "Blue Ocean Strategy," true differential advantage is achieved by creating unique value and experience that competitors do not offer [Kim, W. C., & Mauborgne, R. (2005). *Blue Ocean Strategy*. Harvard Business School Press, pp. 4–9]. Innovative creativity includes the following processes:

Creating new products and services: adapting to existing market demands while discovering new needs and experiences.

Introducing technological innovations: bringing the brand closer to the consumer through AR/VR, interactive platforms, mobile applications, and other innovative tools.

Interpreting the market in a new way: creating unique value and experience that competitors do not offer.

We can see this in the example of Dyson: futuristic industrial design, wireless technology, and the use of laser technology to detect dust in vacuum cleaners are all products of creative innovations that create a unique consumer experience [Kotler, P., & Keller, K. L. (2012). *Marketing Management*. Pearson, p. 263].

4. Emotional and Symbolic Advantage

Neuromarketing research shows that 95% of consumers' purchasing decisions are made unconsciously, that is, at an emotional level [Morin, C. (2011). "Neuromarketing: The New Science of Consumer Behavior." *Society*, Vol. 48, No. 2, pp. 131–135]. Through a creative approach, a brand gains the opportunity to create an emotional experience for consumers, shape loyalty, and reflect a lifestyle.

Symbolic advantage is a strategic tool that reflects the meaning, values, and social position of a brand [Aaker, D. A. (1991). *Managing Brand Equity*. Free Press, p. 39]. For example, Nike's slogan "Just Do It" is not merely an advertisement for shoes; it expresses a philosophy of action, aspiration, and overcoming oneself. For this reason, Nike sells approximately 800–900 million pairs of shoes every year.

LEGO construction sets are also a vivid example of symbolic advantage. These toys are bought not only by children, but also by adults, because they provide nostalgia and creative pleasure and are perceived as a symbol of creative thinking and endless possibilities [Kapferer, J.-N. (2008). *The New Strategic Brand Management*. Kogan Page, pp. 105–112].

5. Brand Equity and Sustainable Competitiveness

Brand equity is the value of a brand created in the consumer's mind, including its recognition, loyalty, and the totality of positive impressions. It is considered a key tool for strengthening market position [Sobirova, G. (2025). *Fundamentals of Marketing: Branding and Strategy*. Tashkent: Universal Publishing, pp. 88–96]. Aaker (1991) identifies the following main components of brand equity:

Brand awareness: the consumer's ability to recognize the brand quickly and distinguish it from others.

Brand image and meaning: the perceptions and emotions that the brand evokes in the consumer's mind.

Consumer loyalty: the consumer's repeated choice of the brand and trust in it.

Differential advantage, perceived quality, and uniqueness: the extent to which the brand stands out from competitors as a product or service.

When brand equity is strengthened through creative strategies, the brand becomes not only visible, but also an object with reliable and sustainable value in the consumer's mind [Obidova, A. (2025). *Brand Creation and Marketing Strategies*. Tashkent: Ilmiy Nashrlar, pp. 54–61].

Discussion

The analysis shows that creativity is not only a visual or advertising tool, but also a strategic factor that strengthens brand competitiveness. Creative brand identity helps consumers recognize and remember a brand more easily, while storytelling creates emotional connection and trust. Innovative creativity allows brands to offer unique value and differ from competitors in the market. Emotional and symbolic elements are especially important because consumers often make purchasing decisions based on feelings, associations, and personal identification with the brand. Therefore, creativity directly contributes to brand equity, consumer loyalty, and long-term market stability. For this reason, creativity should be integrated into all stages of brand strategy, including design, communication, product innovation, and digital interaction with consumers.

Conclusion

In the modern market, where competition is intensifying, creativity is becoming the main strategic factor of a brand. It distinguishes the brand visually and conceptually, creates an emotional connection with the consumer, and ensures differential advantage. A creative approach turns a brand not into a simple product mark, but into a source of value and experience. As a result, brand equity is strengthened and long-term competitiveness is ensured.

Based on the analysis conducted, the following conclusions were formed:

Creativity is a multifaceted strategic factor that harmonizes brand identity, communication, and product innovation.

Creativity is superior to other methods in forming emotional and symbolic advantage because it establishes a deep psychological connection with the consumer.

To form sustainable brand equity, creativity must be consistently integrated into all stages of brand strategy.

Recommendations

Creativity should be integrated into all stages of brand strategy.

Brand identity and communication should be carried out on the basis of a unified concept.

It is advisable to strengthen emotional connection with consumers through innovative and digital tools.

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STUDYING RISK ISSUES IN PHARMACEUTICAL ENTREPRENEURIAL ACTIVITY

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https://doi.org/10.5281/zenodo.20068097

Abstract. *This article provides a comprehensive analysis of the economic, social, and legal aspects of risks encountered in pharmaceutical entrepreneurial activity. The pharmaceutical industry is a high-technology, science-based field operating under strict regulatory control, and the level of risk in this sector is considerably higher than in many other industries. The effective organization of a risk management system is of great importance for the sustainable development of pharmaceutical business and for the uninterrupted satisfaction of the population's demand for medicines.*

Keywords*: pharmaceutical economics, risk, counterfeit medicines, risk level, market share.*

Introduction

The pharmaceutical industry is a strategically important sector in the healthcare system of every country. This field not only satisfies the population's need for medicines but is also regarded as one of the important drivers of the national economy. In recent years, the participation of small and medium-sized business entities in the pharmaceutical sector has been increasing. Such entities have advantages such as flexibility in production, innovative approaches, and rapid adaptation to market demand, and they play an important role in creating import-substituting medicines within the country. At the same time, small business entities have launched the production of phytotherapeutic products, biologically active supplements, cosmetic products, and medical devices, which serve to meet the needs of the population at the regional level [1].

Risk Management

Risk management is the process of identifying what may go wrong in a business, how likely it is to occur, and what can be done to prevent or minimize its impact. In other words, it means protecting operations, financial resources, and long-term business goals before a threat causes damage [2].

In managing the distribution of profits in a small business, the main task is to determine a rational ratio between the part of profit directed toward accumulation and the part directed toward consumption. If all the profit of a small enterprise is directed toward consumption, production may decline due to equipment depreciation and increased repair costs for fixed production assets. Directing most of the profit toward expanding production is also not always the best solution, because this may reduce wage and social expenditure, lower workers' material motivation, and, in turn, lead to the departure of qualified personnel and a decline in income in the future [3].

The illegal sale of medicines through other channels, theft, counterfeiting, and fraud are serious problems that may lead to severe legal and economic consequences for healthcare and pharmaceutical organizations. If these issues are not taken seriously, they may also cause serious reputational damage.

Counterfeiting

Counterfeit medicines are also a major problem. Counterfeit medicines may look authentic, but they may contain little or none of the active pharmaceutical ingredients (APIs) indicated on the label, an incorrect amount of API, low-quality API, contaminants, or repackaged expired products. Such counterfeit medicines pose a serious threat to unsuspecting patients.

The most commonly counterfeited types of medicines include:

- Various chemotherapeutic medicines
- Antibiotics
- Vaccines
- Medicines for erectile dysfunction
- Weight-loss products
- Hormones
- Painkillers
- Steroids
- Antihistamines
- Antiviral agents
- Anti-anxiety medicines

Those deceived into purchasing counterfeit medicines include consumers who misuse medicines or seek to buy medicines at discounted prices. In addition to being very cheap to produce, counterfeit medicines closely resemble genuine medicines, with nearly identical labels and tablets, thereby deceiving unsuspecting pharmacists and patients. It has been reported that counterfeiters use cheap and sometimes harmful materials, such as brick powder, drywall, and flour, to make their fake tablets. Insufficient control and lack of security measures to prevent the theft and misuse of medicines may affect any pharmaceutical company, especially when a facility holds large stocks [4].

Importance

In the pharmaceutical and life sciences sector, risk assessment is very important for the following purposes:

- Patient safety: ensuring that products do not harm patients when used as intended.
- Regulatory compliance: ensuring compliance with international guidelines such as ICH Q9, FDA requirements, and EMA requirements.
- Product quality: minimizing variability in production and ensuring that product characteristics meet established specifications.
- Cost management: proactively addressing risks reduces the likelihood of costly recalls, compliance penalties, or production delays.
- Support for innovation: facilitating informed decision-making during research and development and product life-cycle management.

Principles and Methods

The risk assessment process usually includes the following stages and principles:

Main principles

- Risk identification: identify all potential risks related to product quality, patient safety, and process integrity.
- Risk analysis: evaluate the probability and severity of identified risks using qualitative or quantitative methods.

- Risk evaluation: compare the level of risk with established acceptance criteria to determine its significance.
- Risk control: take measures to reduce, mitigate, or eliminate risks.
- Risk communication: exchange information among stakeholders such as regulatory authorities, internal teams, and external partners.
- Risk review: periodically reassess risk elements throughout the product life cycle [5].

Expiration of Patents for Medicines

Patent cliffs occur when the patent protecting certain medicines expires, allowing generic competitors to enter the pharmaceutical market with a medicine previously protected by another company that had been able to maintain a monopoly and set high prices. In the coming years, many companies are expected to experience a decline in sales due to patent cliffs. After several patent expirations, many pharmaceutical organizations are losing their market share to generic companies that are now able to manufacture medicines that were previously patented. Because companies lose exclusivity, some of them face a situation in which they must develop new medicines or create new strategies in order to remain in the market [6].

Current Policy Context and Sectoral Development

On March 5, 2026, under the chairmanship of Shavkat Mirziyoyev, a videoconference meeting was held on the development of the pharmaceutical sector, expansion of production, and acceleration of the introduction of technologies. At this meeting, special attention was paid to the strategy provided by the state for the sector, because the pharmaceutical industry is viewed not only as an economic sector but also as a strategic direction directly related to public health and the country's overall security.

At the meeting, it was noted that over the past nine years, more than 1.8 billion US dollars had been invested in pharmaceutical production, 140 new production facilities had been launched, and more than 300 enterprises were continuing their activities. The volume of domestic product production increased by 3.5 times, and pharmaceutical exports reached the markets of more than 55 countries.

The meeting set the tasks of attracting at least 1 billion US dollars of investment to the sector this year, increasing the share of domestic products in the internal market to 70 percent by 2030, and raising export volume to 1 billion US dollars over the next five years [7].

Conclusion and Recommendations

Risks in pharmaceutical entrepreneurial activity are multifaceted and complex in nature. To manage them effectively, it is necessary to introduce a quality management system based on international standards, ensure financial stability, and diversify the supply chain. Therefore, it is recommended that young entrepreneurs always take into account the need to solve these problems in their activities with the help of the principles and methods discussed above.

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THE DEGREE OF DIGITALIZATION AND EFFICIENCY OF PUBLIC SERVICES PROVIDED TO THE POPULATION IN THE PROCESS OF DEVELOPING THE ELECTRONIC GOVERNMENT SYSTEM

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https://doi.org/10.5281/zenodo.20842424

Abstract. *In the process of developing the e-government system, the level of digitization and efficiency of public services provided to the population are of great importance. Through the introduction of digital technologies, public services become faster, more transparent and more efficient, expanding the rights and opportunities of citizens. The "Single Interactive Public Services Portal", created in the Republic of Uzbekistan based on the concept of e-government, provides the population with many services online. This article analyzes the stages of development of the e-government system, international experience, existing problems and ways to solve them.*
Keywords: *e-government, digitization, public services, efficiency, transparency, digital transformation, single portal, innovation, international experience, digital literacy.*

Introduction. Today on the day information - communication technologies intense horses with society develops of life various to the fronts current Modern in society state management social processes and subjects between relationship with integral It is related . people joint activity to unite , to coordinate aimed at and organization to the character has . State and society effective cooperation for state management in the field innovations necessary , most modern information and management from technologies use necessary .

The development of the electronic government system is considered one of the most important areas of public administration today. Digital transformation processes are bringing about profound changes not only in the economic sphere, but also in all aspects of social life. In this regard, the level of digitization and efficiency of public services provided to the population is one of the important indicators of social development. The electronic government system serves to effectively organize interactions between citizens, business entities and state bodies through digital technologies. The relevance of this process is that it allows for the prompt and transparent provision of public services, the reduction of bureaucratic obstacles, and the expansion of citizens' participation in public administration [3].

The concept of e-government is theoretically based on three main principles: first, the level of digitization - the complete electronic transfer of public service processes, automation of document flow and management through unified platforms; second, efficiency - saving time and resources, improving the quality of service provision, reducing corruption; third, transparency - providing citizens with open information, creating the opportunity to monitor the activities of state bodies. These principles determine the theoretical basis of the e-government system , and their implementation in practice fundamentally changes the quality of public administration [10].

"Electronic government" is a system of organizational and legal measures and technical means aimed at ensuring the activities of state bodies in providing public services to individuals and legal entities through the use of information and communication technologies, as well as interdepartmental electronic cooperation."

The “Single Interactive Public Services Portal”, created in the Republic of Uzbekistan based on the concept of e-government, provides the population with a wide range of services online. This is an important factor in improving the quality of public services, expanding the rights and opportunities of citizens, and developing digital literacy in society. Another aspect of relevance is that the e-government system allows for adaptation to international experience, integration into global standards, and the introduction of innovative technologies. The experience of countries such as Estonia, South Korea , and Singapore shows that the e-government system not only simplifies public services, but also has a significant impact on economic growth and social stability [15].

At the same time, there are also problems in the development of the e-government system. The insufficient development of technical infrastructure, the need to improve the skills of personnel, and the need to expand the digital literacy of the population are among the pressing issues. By solving these problems, the e-government system can become more effective and sustainable.

Research on e-government development:

1. Janet A. Franklin: Increasing citizen engagement and transparency in government.
2. Richard Heeks: Developing and evaluating e-government models in developing countries.
3. Marijn Janssen: Integrating government information systems, security and continuity.
4. Jane Fountain: Improving e-government effectiveness through social and technological transformation.

In the process of developing the e-government system, the level and efficiency of digitization of public services is the most important condition for ensuring the socio-economic development of society, expanding the rights and opportunities of citizens, and strengthening the transparency of public administration. Therefore, this topic is relevant both theoretically and practically, and its in-depth study and development remains one of the priority areas of state policy.

the level of digitization and efficiency of public services provided to the population in the process of developing the e-government system is based on several theoretical and practical factors. First, modern public administration cannot function effectively without digital transformation. By transferring public services to electronic form, citizens' rights and opportunities expand, they do not spend unnecessary time and money on contacting state bodies. Second, the digitization process ensures transparency, reduces corruption , and makes the activities of state bodies accessible to citizens. Third, the e-government system increases economic efficiency, allows for rational use of resources , and improves the quality of public administration.

The figure below shows the ranking of the development of "E-government" in the world's countries (2022).

International ratings and indices is regularly heard. Thanks to this approach, positive indicators are being recorded in a number of international ratings. In particular, Uzbekistan has risen by 6 places in the e-government rating and joined the Very High EGDI group of the index. Taking into account the 18-place increase in the previous rating, it has risen by 24 places in two ratings. The ranking indicators are the results of the 2024 UN E-Government Survey, which presents the development status of e-government in 193 UN member states, published by the UN Department of Economic and Social Affairs (UNDESA) under the title "Stimulating digital

transformation for sustainable development". According to the results of 2022, Uzbekistan ranked 69th in this ranking with a value of 0.7265, while in 2024 it rose by 6 places to 63rd place with an index of 0.7999. This result indicates that the target indicators of the "Digital Uzbekistan - 2030" strategy have exceeded the value of 0.75 set for 2025 [8].

Place	States	Scope of Services
1	Denmark	97.17%
2	Finland	95.33%
3	South Korea	95.29%
4	New Zealand	94.32%
5	Iceland	94.10%
6	Sweden	94.10%
7	Australia	94.05%
8	Estonia	93, 93 %
9	The Netherlands	93.84%
10	USA	91.51%
69	Uzbekistan	72.65%

Figure 1. Rating of the development of "E-government" of countries around the world (2022)

The e-government system is considered not only a matter of technical infrastructure and software, but also an important factor in socio-economic development. It allows developing digital literacy in society, introducing innovative technologies and adapting to international experience. The experience of countries such as Estonia, South Korea and Singapore shows that through the e-government system it is possible to simplify public services, accelerate economic growth and expand citizen participation in public administration.

Therefore, the development of the e-government system and the analysis of its effectiveness are urgent issues for Uzbekistan, and the reforms carried out in this direction are of great importance in ensuring the socio-economic development of society.

The e-government system is considered the most important component of modern public administration. It serves to effectively organize the interaction between citizens, business entities and government bodies through digital technologies. Theoretically, the concept of e-government is based on three main principles: **the level of digitization** , **efficiency** and **transparency** . When implemented in practice, these principles will fundamentally change the quality of public services, expand the rights and opportunities of citizens, and develop digital literacy in society [12].

The theoretical foundations of e-government are that it interprets public administration not only as a technical process, but also as a social and institutional transformation. Through the introduction of digital technologies, public services become faster, more transparent and more efficient, and citizens' participation in public administration expands. Therefore, the e-government system is one of the important indicators of the development of modern society.

In recent years, reforms have been implemented in the Republic of Uzbekistan to develop the e-government system. For example, during the first half of this year, 2,690 applications were received from individuals and legal entities through public service centers and the “Single

Interactive Public Services" portal, and the execution of these applications was ensured in a timely manner [8].

In particular, 97 applications were received for state registration and re-registration of agricultural, land reclamation and road construction equipment, 2,569 for obtaining a certificate of registration, 7 for deregistration and 17 for temporary registration, and the execution of these applications was ensured within the specified time frame [4].

If we turn to international experience, Estonia is one of the countries that has most successfully implemented the e-government system. In Estonia, 99% of all government services are provided online. This allows citizens to save time and money when contacting government agencies. The experience of South Korea is also noteworthy: there, 95% of government services have been digitized through the e-government system , which has played a significant role in increasing the country's economic efficiency. In Singapore, citizens are provided with services 24/7 through the e-government system.

According to a 2023 study by the Center for Economic Research of the Republic of Uzbekistan, services provided through the e-government system have increased citizens' trust in government agencies. 78% of respondents in the study noted the convenience of using e-services, and 65% noted a significant increase in the speed of service provision. At the same time, 52% of respondents noted a decrease in corruption cases [2].

According to the results of 2022, Uzbekistan ranked 69th in this ranking with a value of 0.7265 , while in 2024 it rose by 6 places to 63rd place with an index of 0.7999. This result indicates that the target indicators of the "Digital Uzbekistan - 2030" strategy have exceeded the value of 0.75 set for 2025 [6].

Level of digitization. The level of digitization of the e-government system indicates the extent to which government services have been converted to electronic form. In Uzbekistan, many services have been fully digitized in recent years. For example:

- Tax payments are being made electronically.
- Payments for utility services are being accepted online.
- a passport and ID card are being managed through an electronic system.
- Business registration and licensing processes are being carried out electronically.

These processes are making the daily lives of citizens easier and increasing the efficiency of public services.

The e-government system ensures efficiency in several ways:

- Time savings - citizens do not wait in line to receive government services, all processes are carried out online.
- Cost reduction – unnecessary costs are eliminated in the process of preparing and submitting documents.
- Transparency - all processes are recorded in an electronic system, which reduces corruption.
- Citizen participation - the e-government system ensures the active participation of citizens in public administration.

Estonia, South Korea, and Singapore serves as an important example for Uzbekistan. In Estonia, even electoral processes are carried out online through the e-government system. In South Korea, the e-government system has played an important role in increasing economic efficiency. In Singapore, citizens are provided with 24/7 services through the e-government system. In

Uzbekistan, based on these experiences, the e-government system is also being consistently developed.

There are a number of problems in the development of the e-government system:

- Insufficient development of technical infrastructure.
- The need for staff training.
- The need to expand the digital literacy of the population.

The following solutions are proposed to address these problems:

- Expansion and modernization of technical infrastructure.
- Development of special programs for staff training.
- Implement educational programs to increase the digital literacy of the population.

The e-government system allows for the efficient, transparent and prompt provision of public services. Uzbekistan's experience is developing in line with international standards. Research results, international ratings and practical evidence confirm the relevance and effectiveness of the e-government system. In the future, the system will be further improved by increasing digital literacy, expanding infrastructure and introducing innovative technologies.

Conclusion. The level of digitization and efficiency of public services provided to the population in the process of developing the electronic government system is a pressing issue today not only for Uzbekistan, but also for countries around the world. Digital transformation processes are deeply penetrating all aspects of social life , and public administration is no exception. Therefore, the electronic government system is considered one of the main mechanisms ensuring the effective functioning of a modern state.

In conclusion, it is worth noting that the e-government system brings the interaction between citizens, business entities and state bodies to a new level. The digitization of public services expands the rights and opportunities of citizens, allows them to receive fast, transparent and convenient services. This process reduces corruption, eliminates bureaucratic obstacles and makes the activities of state bodies more accessible to citizens.

Uzbekistan's experience shows that the e-government system is developing consistently. Hundreds of services are being provided to the population online through the "Single Interactive State Services Portal". According to statistics, millions of applications are received through the portal, and most of them are being successfully processed. This confirms the effectiveness of the e-government system in practice. Also, tax payments, utility payments, passport and ID card issuance processes, business registration and licensing processes are being carried out electronically. These services facilitate the daily lives of citizens and improve the quality of state services.

International experience also confirms the effectiveness of the e-government system. Countries such as Estonia, South Korea , and Singapore have successfully implemented e-government systems. In Estonia, 99 percent of all government services are provided online, and in South Korea, the e-government system has played a significant role in increasing economic efficiency. In Singapore, citizens are provided with 24/7 services through the e-government system. These experiences serve as an important example for Uzbekistan.

The results of the study also show the effectiveness of the e-government system. In a study conducted by the Center for Economic Research of the Republic of Uzbekistan, the majority of respondents noted the convenience of using e-services, reported an increase in the speed of service provision , and noted a decrease in corruption. Uzbekistan's rating on the UN e-Government

Development Index is also improving year by year. This indicator confirms the consistent development of the e-government system in the country.

At the same time, there are also problems in the development of the e-government system. The insufficient development of technical infrastructure, the need to improve the skills of personnel, and the need to expand the digital literacy of the population are among the pressing issues. By solving these problems, the e-government system can become more effective and sustainable. In conclusion, in the process of developing the e-government system, the level and efficiency of digitization of public services is the most important condition for ensuring the socio-economic development of society, expanding the rights and opportunities of citizens, and strengthening the transparency of public administration. The e-government system is an integral part of modern society, and its development ensures the integration of the state into the global digital economy. In the future, to further develop the e-government system in Uzbekistan, it is necessary to expand the technical infrastructure, improve the skills of personnel, develop the digital literacy of the population, and introduce innovative technologies. These measures will further improve the e-government system and increase the quality of public services.

Thus, the e-government system not only simplifies government services, but also has a significant impact on the socio-economic development of society. The experience of Uzbekistan is developing in accordance with international standards and In the future, the e-government system will play an important role in the country's digital transformation.

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ORGANIZING PASSENGER TRANSPORT FOR PERSONS WITH DISABILITIES: INTERNATIONAL EXPERIENCE AND CHALLENGES IN UZBEKISTAN

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Abstract. *The article was prepared on the basis of an innovative project within the framework of state scientific and technical programs IL-9124093892 on the topic "Development of methodological foundations for organizing inclusive tourism (on the example of the Kyzyltepa, Nurota and Khatirchi districts of Navoi region)". This article examines the organization of passenger transportation services for persons with disabilities and reduced mobility (PDRM), situating Uzbekistan's current challenges within a comparative international framework. Drawing on official data from the World Health Organization, UNWTO, national transport authorities, and peer-reviewed scholarship, the study benchmarks Uzbekistan against leading practices in the United States, Germany, Japan, South Korea, Spain, and Switzerland, and against its nearest peers Kazakhstan and Kyrgyzstan. The analysis reveals that despite legislative progress — notably the 2020 Law on the Rights of Persons with Disabilities and the 2021 ratification of the UN Convention on the Rights of Persons with Disabilities — implementation remains critically underdeveloped: low-floor bus penetration stands at approximately 12 percent of the urban fleet; a dedicated paratransit system is absent; and the automated fare-concession scheme covers only four cities. Structural problems include weak enforcement of existing norms, insufficient earmarked financing, the absence of a wheelchair-accessible taxi fleet, and a near-total lack of disaggregated monitoring data. The paper concludes with a six-pillar policy agenda — paratransit development, financing reform, digital accessibility platforms, staff training, infrastructure certification, and regional coordination — grounded in transferable lessons from the countries studied.*

Keywords: *persons with disabilities, reduced mobility, paratransit, accessible transport, inclusive mobility, barrier-free infrastructure, Uzbekistan, Central Asia, transport policy.*

1. INTRODUCTION

Mobility is not merely a convenience; for persons with disabilities and reduced mobility it constitutes the precondition for employment, healthcare, education, and social participation. The World Health Organization (WHO, 2023) estimates that 1.3 billion people — 16 percent of the global population — live with significant disability, while a further 50 percent of that group report difficulty accessing transportation [1]. Translated into absolute terms, roughly 560 million people worldwide are effectively excluded from daily life because of transport barriers [2]. This exclusion carries measurable economic costs: the International Labour Organization estimates that economies forgo between 3 and 7 percent of GDP by failing to employ persons with disabilities at rates comparable to the general population, with inadequate transport identified as one of the leading structural barriers [3].

In Central Asia, the challenge is acute. Post-Soviet transport infrastructure was designed without systematic provision for PDRM, and reform has been uneven across the region.

Uzbekistan has recorded remarkable progress in general transport investment — total transport services reached UZS 145.1 trillion in 2024, a year-on-year increase of 8.6 percent [4] — and in tourism, with 8.2 million foreign arrivals in 2024 [5]. Yet these macro-level gains have not translated into commensurate improvement in accessible services for the country's registered disabled population of over 700,000 persons [6], a figure that excludes the substantially larger population of elderly citizens and those with temporary mobility limitations.

The objective of this study is threefold: to document the current state of PDRM transport services in Uzbekistan through quantitative and normative analysis; to extract transferable lessons from a curated set of international comparators; and to formulate a structured policy agenda grounded in those lessons and adapted to Uzbekistan's institutional context.

Scope and structure. The article follows IMRAD conventions. Section 2 reviews theoretical and empirical literature on inclusive transport. Section 3 describes data sources and methods. Section 4 presents findings on Uzbekistan's normative framework, implementation gaps, and performance benchmarks against international and regional comparators. Section 5 discusses findings and derives recommendations. Section 6 concludes.

2. LITERATURE REVIEW

The conceptual architecture of inclusive transport rests on two intersecting traditions. Universal Design, formalized by Mace (1985) and extended to built environments and public services by Steinfeld and Maisel (2012), holds that products and systems should be usable by all people, to the greatest extent possible, without adaptation [7]. Applied to transport, this principle demands that barrier-free access be the design default rather than a retrofit. The Accessibility Chain framework, developed by Bekiaris, Loukea, and Spanidis (2018), refines this by arguing that transport accessibility is only as strong as its weakest link: a barrier-free vehicle is of limited value if the pavement to the bus stop is impassable, or if the stop lacks audible announcements [8].

A complementary strand of research focuses on the relationship between transport access and social outcomes. Park et al. (2023) conducted a systematic review of 47 studies and found that improving transport accessibility for PDRM increased social participation by 23 to 34 percent and employment probability by 18 to 26 percent [9]. Darcy and Dickson (2009) extended the frame to tourism, demonstrating that barrier-free transport functions as an enabling condition for accessible destination development — a finding directly pertinent to Uzbekistan's tourism-led growth strategy [10].

In the paratransit literature, Goodwill and Joslin (2013) provide a comprehensive review of demand forecasting for door-to-door specialized services, while Gebresselassie (2024) examines why app-hailed transport — despite its theoretical potential — continues to fail wheelchair users, largely because wheelchair-accessible vehicle (WAV) fleets remain a marginal share of ride-hailing supply [11].

The international normative architecture is anchored by the UN Convention on the Rights of Persons with Disabilities (CRPD, 2006), Article 9 of which obligates state parties to ensure access to transportation on an equal basis with others, including by removing barriers [12]. By 2025, 191 states had ratified the CRPD. Uzbekistan acceded in 2021 [6]. The UNWTO‘s ISO 21902:2021 standard operationalizes accessibility requirements for tourism-related transport, encompassing physical, sensory, cognitive, and digital dimensions [13]. At the regional level, the European Union's suite of passenger rights regulations — EC 1107/2006 (air), EC 1371/2007 (rail), and EC 181/2011 (road) — creates a legally binding floor for member-state transport

operators [14]. These instruments collectively define the benchmark against which national systems are assessed in this study.

3. MATERIALS AND METHODS

The study employs a multi-source comparative analysis. Primary quantitative data were drawn from: official statistics of the State Statistics Committee of Uzbekistan and the Ministry of Transport (2020–2024); WHO Global Disability Report (2023); UNWTO Accessibility Guidelines (2023–2024); national transport statistics of Kazakhstan (Bureau of National Statistics, 2024); UNDP Kyrgyzstan Situational Analysis (2023); and peer-reviewed journals including Transport Reviews, Disability and Society, and the Scandinavian Journal of Disability Research.

Country comparators were selected on two criteria: (i) documented excellence in PDRM transport provision (United States, Germany, Japan, South Korea, Spain, Switzerland); and (ii) regional peer relevance (Kazakhstan, Kyrgyzstan). For each comparator, a standardized profile was compiled covering: legal framework, low-floor bus penetration, paratransit provision, wheelchair-accessible taxi fleet, and composite service satisfaction score from published surveys.

A Service Gap Index (SGI) was constructed for Uzbekistan by measuring the distance between actual performance on six indicators and minimum international standards, expressed as a percentage of the required standard. Regression of SGI scores against key policy variables (enforcement mechanisms, earmarked financing, digital integration) allowed identification of the highest-leverage intervention areas.

4. RESULTS

Uzbekistan's legal framework for PDRM transport has been substantially strengthened over the past five years. The 2020 Law on the Rights of Persons with Disabilities mandates: equipping public transport with accessibility aids; installing audio announcements and visual information boards; providing dedicated spaces in rail carriages; and ensuring escort services at airports and major stations. Resolution No. 123 of the Cabinet of Ministers (March 2024) extended the concessionary transport card scheme and mandated its rollout from Tashkent to Samarkand, Urgench, and Qarshi [6]. By 2021, the country had completed ratification of the CRPD, formally accepting the obligations of Article 9.

Despite this legislative progress, implementation falls critically short. The automated fare-payment system — an important prerequisite for contactless concessionary card use — has been deployed in only four cities, with 3,107 validators installed and 555,000 cards issued [6]. The Afrosiyob high-speed rail service includes designated seats for PDRM in each carriage, and Tashkent's metro system provides audio-visual announcements on trains. However, only approximately 35 percent of metro stations possess functional lift access, and the share of low-floor (step-free entry) buses in the national urban fleet is estimated at around 12 percent — a figure derived from operator procurement data and corroborated by academic surveys of users in Tashkent [17].

Table 1. Uzbekistan: Key PDRM Transport Indicators versus International Standards (2024)

Indicator	Uzbekistan (actual)	Minimum standard*	Gap (pp)	Rating
Low-floor urban bus share, %	12	≥60	48	Critical
Metro stations with lift access, %	35	≥80	45	Critical
Designated rail carriage spaces per train	Partial	≥4/carriage	n/a	Moderate
Paratransit (door-to-door) system	Absent	Present	100	Very critical
Wheelchair-accessible taxis (WAV), units	0	≥200/city	100	Very critical
Concessionary card city coverage	4 cities	Nationwide	70%	Serious
Enforcement / monitoring mechanism	Weak	Statutory audit	n/a	Serious

** Standards derived from EU transport accessibility regulations, UNWTO ISO 21902:2021, and WHO Good Practice benchmarks.*

Synthesis of normative analysis, indicator benchmarking, and user-level survey evidence points to six interconnected structural problems in Uzbekistan's PDRM transport system:

Absence of a paratransit system. Uzbekistan has no door-to-door specialized transport service comparable to the ADA paratransit network in the United States or Germany's subsidized ridepooling. PDRM who cannot use standard fixed-route services have no publicly funded alternative. This represents the single largest gap relative to international norms.

Critically low low-floor vehicle penetration. With approximately 12 percent of urban buses meeting step-free entry standards, PDRM who use manual wheelchairs or mobility aids are effectively excluded from the majority of urban bus routes. The internationally accepted minimum threshold is 60 percent; peer Kazakhstan has already reached 79 percent.

No wheelchair-accessible taxi fleet. Seoul, a comparator city, operates 747 wheelchair-accessible call taxis; Germany's Hamburg introduced on-demand wheelchair-accessible ridepooling in 2023. In Uzbekistan's cities, there is no dedicated wheelchair-accessible taxi service, and the main ride-hailing platforms (Yandex, Uber) offer no WAV option.

Fragmented digital accessibility. The concessionary card system, though expanding, covers only four cities. No national real-time platform maps barrier-free routes, lift-operational status at metro stations, or accessible taxi availability — tools that Japan (BFTIS), Spain (AccessibleSpain), and South Korea have deployed at national scale.

Weak enforcement and monitoring. The 2020 Law's mandates carry no statutory financial penalty for non-compliance by transport operators. No annual accessibility audit is published. The registered disability count (700,000+) does not disaggregate by mobility type, making evidence-based planning difficult [6].

Insufficient earmarked financing. Transport sector investment has grown consistently, but PDRM-specific appropriations remain opaque and unquantified in public budget documents. Vehicle procurement subsidies that condition import-duty waivers on accessibility compliance — a mechanism used in Germany, Japan, and Kazakhstan — do not currently exist.

Table 2. International Comparator Profiles — PDRM Passenger Transport (2023–2024)

Indicator	USA	Germany	Japan	S. Korea	Spain	Switzerland
Legal anchor (year)	ADA, 1990	BGG, 2002	BFT Law, 2006	DRA, 2007	LISMI, 1982	DDA, 2004
CRPD ratified	2009	2009	2014	2008	2007	2014
Low-floor bus, %	99.1	82	76	70	71	80
Paratransit system	Yes (ADA)	Yes (MOIA)	Yes	Yes	Partial	Yes (DDA)
WAV taxis (units)	50,000	200 (Hamburg)	Extensive	747 (Seoul)	Broad	500
Acc. satisfaction (0–10)	7.4	8.1	7.8	7.8	7.6	8.3
Earmarked subsidy	Federal	Federal+State	National	National	National+NGO	Cantonal

Sources: [11; 15; 16; 17; 18; 19; 20; 21]. Satisfaction data from national user surveys cited in respective country sources.

Among Uzbekistan's immediate neighbours, Kazakhstan provides the most instructive benchmark, having invested substantially in PDRM transport since the mid-2010s. By 2025, 79 percent of city buses and 80 percent of bus stations in Kazakhstan met accessibility requirements, and the Invataxi paratransit fleet had grown 30 percent to reach 1,426 specially adapted minivans nationwide [22]. The government's declared target is for 68 percent of all social infrastructure facilities — 29,500 of them by 2025 — to be accessible to persons with disabilities, with a further increase to over 34,000 facilities by end-2026 [22]. On paper, Kazakhstan's regulations specify narrow corridor widths in adapted intercity buses, forward-facing wheelchair spaces, level floors in wheelchair zones, and trained staff; in practice, the NGO Accessible Kazakhstan notes that 57 percent of rail tracks remain in substandard condition and adapted carriages represent a minority of the fleet, illustrating that even a more advanced peer faces implementation gaps [23].

Kyrgyzstan occupies a different position on the reform trajectory. The CRPD was ratified only in 2019, and the comprehensive state programme 'Accessible Country 2023–2030', approved in February 2023, constitutes the primary policy vehicle for disability access across all sectors,

including transport [24]. The programme is ambitious in scope but limited by resource constraints; UNDP's 2023 situational analysis found that the gap between legislative commitment and ground-level implementation remains wide, with accessible urban transport a particular weakness [24]. Kyrgyzstan's experience confirms that CRPD ratification alone is insufficient — institutional capacity, financing, and enforcement mechanisms are equally critical.

Table 3. Central Asian Regional Comparison — PDRM Transport Indicators (2024)

Indicator	Uzbekistan	Kazakhstan	Kyrgyzstan
CRPD ratification year	2021	2015	2019
Low-floor urban bus share, %	12	79	8
National paratransit scheme	Absent	Yes (Invataxi)	Pilot stage
Accessible infrastructure (%)	30-40	68	<20
Concessionary card coverage	4 cities	Major cities	Bishkek only
National monitoring framework	Absent	Partial	Under development
Persons with disabilities (est.)	>700,000	>700,000	>160,000

Sources: [6; 22; 23; 24; 25] and national statistical agencies.

5. DISCUSSION

The six advanced-country comparators share four structural features that drive their superior performance, each transferable — with adaptation — to the Uzbek context.

(a) Legally anchored, financially backed paratransit. The United States ADA obligates every transit agency operating fixed-route services to provide complementary paratransit within a three-quarter-mile corridor at a fare no more than twice the fixed-route fare. The Federal Transit Administration's annual paratransit data show a 7 percent increase in trip volumes between 2007 and 2010, demonstrating suppressed demand that activates rapidly once service exists [15]. Germany's Hamburg demonstrated in 2023 that on-demand ridepooling platforms can be extended to PDRM at modest marginal cost once a city-wide ridepooling infrastructure exists: MOIA integrated wheelchair-accessible vehicles and subsidized fares for persons with severe disabilities as a 'last-mile' complement to fixed-route transit [16]. Both models confirm that paratransit need not be fiscally prohibitive when structured as a supplement to rather than a replacement for mass transit.

(b) Fleet transformation through procurement standards and incentives. The U.S. (99.1% low-floor penetration), Germany (82%), Japan (76%), and Spain (71%) all achieved high low-floor shares through mandatory vehicle standards applied to new procurement, combined with accelerated depreciation rules and import subsidies for compliant vehicles. Japan's Barrier-Free Transport Act (2006) set rolling targets for each transport mode, reviewed every five years — a ratchet mechanism that prevented backsliding [17]. South Korea's 2024 survey confirmed that nationwide low-floor bus penetration reached 44.4 percent, with Seoul at 71 percent, driven by mandatory fleet replacement schedules and municipal procurement grants [18].

(c) Integrated digital accessibility ecosystems. Japan's Barrier-Free Travel Information System (BFTIS), deployed nationally from 2024, provides real-time maps of lift operational status, step-free routes, and WAV taxi availability. Spain's AccessibleSpain platform performs a comparable function for tourism-related transport. South Korea's national accessible-transport app integrates call-taxi booking, audio navigation, and route planning for PDRM [19]. These platforms do not merely convey information; they generate demand data that governments and operators use for network planning — a feedback loop absent in Uzbekistan.

(d) Financial penalties and statutory audits. Switzerland's Disability Discrimination Act (DDA, 2004) required all existing transport vehicles to be upgraded by 2024, with fines for non-compliant operators ranging from CHF 5,000 to CHF 50,000 per vehicle. The European Union's passenger rights regulations impose compensation obligations on carriers that fail to provide required assistance [14]. Without financial consequences, as Kyrgyzstan's experience illustrates, legislative mandates remain aspirational [24].

Kazakhstan's trajectory is particularly instructive for Uzbekistan because it demonstrates what a Central Asian economy at a comparable income level can achieve within a decade of committed investment. The 30 percent growth in the Invataxi fleet — reaching 1,426 vehicles — shows that a national paratransit scheme is operationally feasible in the region. Kazakhstan achieved 79 percent low-floor bus penetration through a combination of mandatory procurement rules applied to new bus orders and targeted financing through the Social Entrepreneurship Corporation. The gap between Kazakhstan and Uzbekistan on low-floor penetration (79 vs. 12 percent) is not primarily technological; it reflects different institutional choices — financing mechanisms, procurement conditionality, and enforcement — that Uzbekistan can replicate.

Equally instructive is Kazakhstan's honest self-assessment: the NGO 'Accessible Kazakhstan' openly documents the gap between regulation and practice, particularly in rail accessibility (57 percent of tracks substandard) and adapted carriage supply [23]. This suggests that even best-in-region performance in Central Asia falls considerably short of OECD norms, and that monitoring transparency — which Kazakhstan has advanced further than Uzbekistan — is a prerequisite for iterative improvement.

Uzbekistan faces three constraints that partially distinguish its reform challenge from the OECD comparators. First, its vehicle manufacturing base is skewed toward privately-owned Chevrolet-branded passenger cars, with bus and specialized vehicle production underdeveloped; WAV procurement therefore depends heavily on imports, making tariff policy a first-order reform lever. Second, spatial dispersal — with major cities separated by hundreds of kilometres across steppe and desert — means that rural PDRM have virtually no alternative to private or informal transport; any paratransit scheme will need to prioritize urban areas first before addressing intercity gaps. Third, the institutional capacity to administer complex subsidy and procurement programmes is concentrated in Tashkent and a few provincial capitals; a phased rollout that builds capacity progressively is more realistic than a simultaneous national deployment.

Counterbalancing these constraints are genuine advantages. The 2030 National Development Strategy explicitly prioritizes social inclusion and transport modernization. The automated fare-payment system already in place in four cities provides a technological foundation on which concessionary card and booking systems can be built. The country's expanding tourism infrastructure creates a business case for accessible transport that goes beyond social policy: UNWTO data show that accessible tourism generates premium yield per visitor and longer average stays, aligning PDRM transport investment with commercial tourism strategy [13].

6. CONCLUSIONS AND RECOMMENDATIONS

This study has documented a significant and multi-dimensional gap between Uzbekistan's formal commitments to PDRM transport rights and the lived experience of persons with disabilities navigating the country's transport system. The gap is not attributable to resource scarcity alone; Kazakhstan, operating under comparable fiscal constraints, has achieved dramatically better outcomes by embedding accessibility requirements in procurement conditionality, creating a national paratransit fleet, and investing in enforcement capacity. The following six-pillar policy agenda translates the comparative evidence into actions calibrated to Uzbekistan's institutional context.

Establish a National Paratransit System (2025–2028). Pilot a door-to-door specialized transport service (Invataxi model) in Tashkent in 2025 with an initial fleet of 150 WAVs, subsidized at 70 percent of cost for eligible PDRM. Scale to Samarkand and other major urban centres by 2026–2027, targeting 500 vehicles nationally by 2028. Integrate booking through a single national app. Finance through a PDRM Transport Fund drawing on: (i) redirected import-duty waivers on WAV and low-floor bus procurement; (ii) a 0.5 percent transport operator licence surcharge; and (iii) co-financing from ADB's social infrastructure programme and UNDP's inclusive growth cluster.

Mandatory Fleet Transformation Schedule. Require that all new urban bus procurement from 2026 comply with low-floor entry standards, targeting 40 percent of the urban fleet by 2028 and 70 percent by 2032 — replicating Kazakhstan's procurement conditionality. Extend import-duty exemptions (currently zero for a limited vehicle category list) to low-floor buses and WAVs regardless of origin. Introduce a five-year rolling target framework, reviewed annually and published online, replicating Japan's Barrier-Free Transport Act ratchet mechanism.

Deploy a National Digital Accessibility Platform. Build on the existing automated fare-payment infrastructure to launch an 'UzAccess' mobile and web platform by end-2026, providing: real-time lift and ramp status at all metro stations; accessible route mapping for all cities covered by concessionary cards; WAV taxi booking with priority dispatch; and multilingual audio navigation (Uzbek, Russian, English). Co-design the platform with disability organisations. Feed anonymized demand data to the Ministry of Transport's network planning unit — replicating Japan's BFTIS feedback loop.

Introduce Financial Enforcement Mechanisms. Amend the 2020 Law on the Rights of Persons with Disabilities to impose graduated administrative fines on transport operators whose fleet or infrastructure does not meet statutory accessibility requirements: UZS 50 million per non-compliant vehicle in Year 1, rising 10 percent annually. Mandate an annual accessibility audit by an independent technical body, with results published in the Ministry of Transport's online open-data portal. Replicating Switzerland's DDA model, set a 2030 hard deadline for full statutory compliance.

Mandatory Staff Training and Certification. Require all urban bus drivers, rail station platform staff, airport assistance personnel, and taxi drivers registered on ride-hailing platforms to complete a certified PDRM assistance module — minimum eight hours — as a condition of licence renewal. Develop the curriculum in partnership with UNDP and the International Labour Organization's Decent Work programme. Establish a national register of certified accessible-transport providers, publicly searchable, to create reputational incentives for compliance.

Regional Coordination and Knowledge Transfer. Establish a Central Asian Accessible Transport Working Group under the SCO or CIS transport coordination mechanism, with

Kazakhstan as the initial chair given its comparative experience. Commission a biennial regional benchmark report — analogous to the EU's Accessible EU reports — tracking low-floor bus penetration, paratransit fleet size, WAV availability, and user satisfaction across participating countries. Institutionalise staff secondments between the Uzbek Ministry of Transport and Kazakhstan's Ministry of Industry and Infrastructure for knowledge transfer on Invataxi management and procurement conditionality.

Implemented sequentially over a five-year horizon, this agenda is estimated to raise Uzbekistan's composite PDRM Transport Service Index from its current ~3.2/10 to approximately 6.0/10 — broadly comparable to Kazakhstan's present level and consistent with the country's CRPD obligations and 2030 development targets. The incremental cost is substantial but not prohibitive: international experience suggests that a national low-floor bus transformation programme and a city-scale paratransit pilot, combined, can be financed within two to three percent of total annual transport sector investment when procurement conditionality and duty waivers replace direct subsidy as the primary policy instrument.

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CURRENT ADOPTION LEVELS AND INTERNAL CHALLENGES OF SUSTAINABLE MANAGEMENT PRACTICES IN THE HOTEL SECTOR IN UZBEKISTAN

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Abstract. *This study investigates hotels in Samarkand, Uzbekistan, which are using sustainable practices. It looks into the current level of sustainable practices adopted by the hotel industry, since they are experiencing a large increase in tourism, pressurizing them to find ways to minimize environmental damage, through the usage of energy, water, and waste. The research used a quantitative descriptive study method and collected data from 60 hotel managers and staff using structured questionnaires. It measured sustainable practices adopted by hotels based on these four areas: energy, water, waste, and local sourcing; and wanted to identify what financial, government, and staff related barriers existed to sustainable practice adoption.*

Findings showcase that the adoption of sustainability is low to moderate at present and the most common practices include energy saving measures such as LED lighting and smart key-cards because of the immediate cost savings. However, there are a lack of water conservation and waste management systems in hotels. In terms of barriers, 38.3% of respondents identified limited financial resources, 40.8% a lack of training of employees, and 66.7% inadequate enforcement of laws as the primary reasons to further adopt sustainable practices. However, when statistical analysis was done to test these barriers np significant correlation was found between the specific barriers to actual sustainability adoption rates.

The study suggests that hospitality business owners did not yet fully recognize the importance of operating in a sustainable manner and its benefits in the long-run, despite the initial high expenses. It also urges the hotel operators to look deep into the issue and create regulatory network developments and for the government to offer financial incentives to encourage those in the hospitality business to further adopt sustainable initiatives.

Keywords: *Sustainable Management Practices; Tourism; Green Hotel; Adoption levels; Internal Challenges; Eco-conscious consumers; Triple bottom line;*

CHAPTER ONE: INTRODUCTION

1.1 Introduction

Tourism is one of the largest industries around the world which is growing at an unprecedented rate, requiring a great attention for business entities to upgrade and maintain its sustainability practices. This is especially relevant for the hospitality sector, where sustainable practices have been gaining importance with rising global recognition of environmental, social, and economic factors. According to the estimates, the scope of tourism sector is getting bigger and by 2034 global GDP will reach $16 trillion by the travel and tourism industry which is the total of more than 11% globally, generating about 30 billion trips (Ly, n.d.). This amount of pressure, to some extent comes down to the lodging industry, which is one of the major energy consumers

costing up to 60% of their utility bills and utilizing it for day-to-day operations like lightning, air conditioning, laundry, etc. However, adopting sustainable management practices can be beneficial for hotels in order to minimize cost and keeping up with the global trend and attracting more environmentally concerned customers (*Blog | Placement International*, n.d.). The simple definition of sustainable management practices in hotels is the implementation of green policies and practices into the lodging sector that ensure to lessen its harmful effects on the nature, foster social initiatives, and maintain financial stability. This approach consists of several key features like supporting local businesses by purchasing local produce, minimize waste generation, efficient water usage, while maintaining the service quality and enriching guest satisfaction. Also, based on the market demand, there are 83% of tourists who consider sustainable and responsible travel as a significant factor and they are the ones that look for an environmentally friendly tourism spots (EHL Hospitality Business School, 2024)**.**

1.2 Research background

Tourism is growing significantly in Uzbekistan, and it has already become a key contributor to economy of the country, especially benefitting the hotel accommodation sector. Overall, in 2023, 5.2 million foreign guests were welcomed to Uzbekistan, which is an increase of 21% compared to the numbers of 2022 and in the consequent year of 2024, it increased to 20.1% respectively (UZSTAT, 2025, p. 1). However, without proper sustainability measure, it poses a great threat to both the environment and the society by causing all types of pollution and deteriorating natural resources. As Uzbekistan is attempting to build the image of an eco-friendly tourist spot, adopting sustainability practices ensure to achieve its long-term vision and minimize the harmful effect of tourism to the environment (Sodikov Mirziyo Odiljon ogli, 2025). Moreover, green certifications and eco-tourism programs have been introduced by the government, and these initiatives mostly focus on the promotion of sustainable energy use in the hospitality sector, improving waste management systems, and implementing environmentally friendly transportation options. Unfortunately, the real challenges still remain which are yet to be looked into the efficient execution of these sustainable initiatives (Usmanovich, 2025).

1.3 Problem Statement and Research Gap

Since Uzbekistan has been facing a rapid growth in the tourism sector, adopting long-term sustainable measures can lessen the harm done to the cultural heritage sites, society, and the environment equally enhancing its potential and resistance against this growth. However, improper sustainable initiatives in vulnerable tourist sites, society and the nature lead to detrimental consequences such as increased pollution, resource scarcity and depletion, heritage site degradation, and tension to the local people (Sodikov Mirziyo Odiljon ogli, 2025). This is particularly relevant to the hotel industry, which is one the major contributors of pollution, resource consumption, and carbon footprint. So, recognizing these urgent patterns made managers adopt number of actions like introducing green management practices, green labels etc. to contribute to sustainability (Popșa, 2023). On the other hand, despite the provided opportunities and initiatives, the hotel sector still faces challenges in adopting sustainable measures, as statistics show that only 20%, or 80 hotels, operate sustainably. These numbers are noticeably lower compared to the leading neighboring country, Kazakhstan, where there are about 150 sustainable hotels, making up 30% overall (Sardor, 2024). In the case of Uzbekistan, in the wider scale, there are several barriers that hinder the further development of sustainability adoptions. The potential challenges include the lack of knowledge and skills in eco-efficient operations and green construction efforts, financial limitations for the initial installations and initiatives, and the need

for the infrastructure improvement in areas like waste reduction and green energy (Sodikov Mirziyo Odiljon ogli, 2025).

Previous studies provide valuable information about general challenges that hinder the sustainable implementations in the tourism industry and suggest several adoption measures. However, there is a lack of empirical data on the adoption levels of sustainable practices and certain internal challenges faced by the hotel management in Uzbekistan, especially in the case of Samarkand. This study is aimed to fill that gap by collecting real-time data and information about the adopted practices and micro-level challenges encountered inside the hotel and barriers to completely switch to sustainable operations.

1.4 Aims and objectives of the research:

Main purpose of my research is to provide information about real-time adoption levels of sustainable measures already implemented in hotels and identify key internal challenges faced by the management towards the introduction of other sustainable practices which are not yet implemented in hotels of Uzbekistan, specifically in Samarkand. Through this research I want to give a clear picture of sustainability in hotels by measuring the sustainability levels and challenges faced to responsible bodies to make an effective decision to further enhance this initiative. The main focus groups of the study are hotels and their employees in Samarkand and the management who is concerned in implementing sustainable practices into hotel operations. Overall, achieving the aim of making Uzbekistan more sustainable is rooted in multiple reasons, for instance, challenges it is facing or may face in the near future in terms of fresh water shortage, its contribution to Climate Change through mainly relying on fossil fuels in operations, air pollution and etc. the contribution I want my research to make is making hotels operate in more sustainable way minimizing its effect on environment, benefitting locals, and being economically viable contributing positively to its surroundings and meeting customers' expectations by being both eco-friendly and improving their satisfaction levels.

In order to achieve expected aims, there are tasks which need to be completed to achieve this. First of all, sustainable measures that are going to be measured are energy, water, waste, local purchases and the adoption levels of hotels categorized be low, medium, high; and specific internal challenges in hotels. The hotels will be chosen randomly and the data will be collected through questionnaires and interviews from hoteliers.

1.5 Research Questions:

Reflecting on aims and objectives there are most important questions that lead to answering my research gap:

1. What sustainable measures your hotel has already implemented in terms of energy, water, waste and sourcing?

2. Define the challenges that the management is facing in implementing sustainable measures which are not have been implemented?

3. What kind of assistance would be most helpful to fully operate your hotel in a more sustainable way?

1.6 Significance of the research:

On a practical note, these research outcomes will help policymakers, tourism authorities, and hoteliers to understand the current levels of adoption of sustainable practices and internal barriers, ensuring viable solutions are put forward. Hotel sector, sustainability consultants, policy makers, and stakeholders stand to benefit this research in their pursuit of enhancing sustainability in the sector by making better and practical decisions. Hotels reduce costs, minimize their

environmental footprint, strengthen brand reputation, support responsible tourism, and gains competitive advantage by shifting towards sustainability.

1.7 Explanation of the Keywords

Tourism: A phenomenon shaped by social, cultural, and economic factors that involves traveling to one location to another outside their regular surroundings for personal or business reasons (*Glossary of Tourism Terms | UNWTO*, n.d.).

Sustainable Management: Running and making wise decisions now to avoid damaging the company with the consideration of people, the environment, and profitability (*Sustainable management definition & top 10 best practices*).

Green Hotel: lodging facilities that place a great emphasis on environmental sustainability by recycling programs, energy and water conservation, and the use of alternative energy sources (chatlyn.com, n.d.).

Waste management: A systematic utilization of unnecessary goods following through the processes of collecting, reprocessing, recovering or disposal. Its main focus is to minimize waste, optimize recycling and reuse, so it reduces damage to the environment and resources being lost (*Waste Management Explained | Agriculture & Sustainability*, n.d.).

Eco-conscious consumers: Consumers who consider the environment and society before making a purchase and opt for goods and services that help to lessen their harmful environmental impact (Loughlin, 2023).

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In the current business environment sustainability plays a crucial role because companies are assessed according their social, environmental, and governance practices along with the organization's financial outcomes. As there is a constant pressure for more business sustainable operations from investors, customer, and regulatory authorities, SMP has become a crucial tool to meet the business's long-term objectives. There are three components of SMP which tackle different aspects of sustainability: Environmental area examines organizations' effective and responsible usage of natural resources by reducing waste, water conservation initiatives, cutting carbon emissions, etc. The social factor includes ensuring transparent labor practices, equality, and ethical business practices that puts emphasis on business's relationship with employees, clients, and local communities. Governance evaluates leadership behaviors, moral principles, fairness, and compliance with legal obligations. On the other hand, environment and society will be under threat of increased pollution, overconsumption of resources, and pressure on locals if there is not a proper sustainability measures, especially in this rapid growing tourism sector. In this case, the development of green infrastructure helps to achieve long-term sustainability goals, particularly in the hospitality sector, which can significantly reduce their environmental footprint and contribute to the tourism industry's overall well-being in the global market (Gayratovna, 2025). As it was mentioned before, the number of eco-conscious consumers are increasing, especially millennials and Gen Z generation, who are rapidly leading the pack in the tourism industry. Therefore, despite facing difficulties it is crucial to take actions at the moment and having competitive advantage over them and staying ahead of the curve that yield to substantial benefits in the long-run. This approach affects guests' decision-making and gives first impression of the brand (Elphick, 2024). SMP especially crucial to implement in the Uzbekistan's condition, partly because of its location where there is predominantly a humid climate, acute water scarcity that primarily used for agricultural activities. Also, natural gas is the main source of energy, making it heavily reliant on

fossil fuels, so the government has started to take necessary actions acknowledging the value of green technologies and enhancing waste management techniques (Shodmonov & Mustafakulov, 2024).

For instance, several articles of "Law on tourism" specifically supports the sustainable tourism initiatives promoting the effective utilization of natural resources and facilities the reduction of its impact on the environment. They include the emphasis on ecotourism and protection of historical monuments, businesses' obligations towards energy conservation and environmentally friendly infrastructure in the hospitality industry, promoting international collaboration and others. The government also adopted some regulations and requirements which involves the cooperation with major hotel chains and government ministries that show the country's dedication towards the integration of sustainable operations in the hotel sector (Gayratovna, 2025).

Overall, the global research reveals that enterprises which incorporate sustainable practices reduce their operational expenses by 15-30%, strengthen their brand reputation and achieve greater customer satisfaction. In 2023, 5.2 million visitors were received in Uzbekistan from abroad which shows 21% rise than the previous year. Nonetheless, the total accommodation sector which adopted green certificates are still lower that 10%, greatly falling from international norms (Safayeva, 2025).

Ho: Hotels in Uzbekistan (specifically in Samarkand) do not have low rate of sustainable management practices.

H1: Hotels in Uzbekistan (specifically in Samarkand) have low/moderate rate of sustainable management practices.

2.2 Theoretical background

Sustainability is about an approach that seeks to preserve the resources for the upcoming generations balancing to satisfy the current demands of people and is considered to focus on Triple Bottom Line (TBL). This stands for making decisions in the organizations that combines three core values like social, environment, and economic. These factors establish the highest degree of sustainable practices across the business environment. According Slaper and Hall environmental aspect of sustainability is about the effort of conserving natural resources and ensure their long-term existence. In terms of sociocultural components in the hospitality sector, it addresses the societal effect of businesses in the industry to residents they are located; the financial element is about optimizing finances within the companies and taking into account the shareholders' needs and objectives. In order to gain the best possible outcomes from sustainable practices it is necessary to incorporate all components of triple bottom line because everything is closely interconnected and the business cannot be classified as sustainable until either of the elements are absent in their operations. However, if only one parameter (environmental) is incorporated then it can be considered as green enterprise not the sustainable one. This kind of behavior often faces controversial standpoint because it greatly impacts the hospitality sector in particular, weakening its long-term viability. Therefore, TBL framework assesses the company's success according their contribution of those three factors (Tokro & Dzitse, 2024).

Green Certification in the Hospitality industry: Green certifications for hotels are third-party programs assessing its environmental and social policies and serves a guarantee to communities, visitors, authorities, and investors for following sustainability standards (Graham, 2025).

There are different types of sustainability certifications each addressing certain areas it, like Global Sustainable Tourism Council, Green Globe; ISO 14001; Green Key; LEED and many more. GSTC standards emphasize sustainable management, socioeconomic, cultural, and environmental implications and take into account global sustainable tourism rules and criterias. The Green Key signifies company's dedication to operate sustainably and standards of environmental accountability established by the Foundation for Environmental Education. LEED evaluates factors like indoor air quality, materials used, energy and water efficiency, and etc. (Hotel Sustainability Certifications, n.d.). And one of the most popular environmental management system (EMS) certification is ISO 14001 and takes active initiatives in order to reduce environmental footprint abide by applicable laws, and accomplish sustainability goals (*ISO 14001 Certification – Environmental Management Systems*, n.d.).

Environmental certifications connect sustainability practices and hotel's competitiveness in the market by showing not only its compliance with sustainability requirements but also lets eco-aware customers know how dedicated they are in terms of efficient resource utilization. It also improves hotel's reputation, boost customer loyalty, increases occupancy rates, and lowers operational costs due to optimized consumption of resources (Velaoras et al., 2025).

If to look at numbers, 75% of travelers worldwide wish to travel in a more environmentally conscious way, and 83% of travelers believe that sustainable tourism is essential to them. Also, it shows that according to 65% of visitors, they feel better staying at a hotel with a sustainability certification; and for 45% of respondents certified accommodations are more desirable (*Green Hotel Certification*, 2025).

2.3 Previous studies:

One of the key aspects of going green for hotels is to minimize the negative impact of the business to the environment, while at the same time providing enjoyable and appealing experience for the guests. For hotels, showing dedication to conserving our world is done by concentrating on sustainability and as a result this approach can attract more eco-conscious tourists. Besides, by adopting necessary steps hotels and organizations may considerably reduce their energy consumption resulting in cost savings in the long-run (Ecobnb, 2023).

Based on the regression results of K. Sardor (Sardor, 2024), there is a significant favorable link between hotel profitability and integrating sustainable management practices into their operation in terms of occupancy rate and profitability. Even though water, energy conservation efforts and local sourcing demonstrated slightly lower impact, the biggest effect had integration on renewable energy usage. Occupancy rate increased because of the higher level of renewable energy practices attracting a great number of eco-conscious travelers. The same came out true in terms of profit margins, hotels that introduced sustainable initiatives like renewable energy and using locally sourced products not solely increased occupancy but also had a significant positive effect on economic condition of hotels. There is a popular belief that hotel sector greatly contributes to the job creation, infrastructure, and society, so the hotels can further stretch its capability of operational performances by adopting sustainable practices (Sardor, 2024).

By being eco-friendly hospitality industry develops a positive brand reputation and it provides a strong competitive advantage that sets them apart from competitors attracting more and more tourists, claim Graci and Dodds. Especially the Gen Z visitors are drawn to this phenomenon and support the sector which are taking steps to reduce waste, energy and water consumptions. Based on the research outcomes the sustainability measures are significantly more likely to be implemented by big hotels compare to smaller ones. This may be due to the fact that necessary

green initiatives have been established to enhance profit ("The Role of Sustainable Management Practices and Social Media in Shaping Generation Z's Preferences for Environment-Friendly Hotels," 2024).

Also, since large hotels have the required financial resources and capabilities it is easier for them to implement sustainable practices and benefit from it. According to van Haastert's study it was very difficult to incorporate sustainability in certain facilities due to the low stakeholder interest in it which is the result of its disconnection from the influence of outside factors. Moreover, there are still some challenges that may become a barrier to hold hotels from putting sustainability into practice like budgetary constraints, insufficient amount of support from higher authorities and government policies. One of the popular concerns of supervisors and executives is the high cost of it to fully shift towards the sustainable practices. Other common obstacles include the minimal awareness level and appropriate knowledge of sustainability and its importance; lack of stakeholder support; limited training opportunities for the employees and many more (Tokro & Dzitse, 2024). In Uzbekistan's case, hotels face certain general issues like the financial obstacles where the shift to sustainability slows down because of the high costs of set-ups of solar and wind power; lack of expertise in a fast-growing sphere, and the qualified experts who are able to operate green energy systems; old and inefficient power grid which is blocking to effectively incorporate alternative energy sources. To promote sustainable practices government has involved by deduction tax and offering subsidies for green energy initiatives. However, despite this effort, in order to reach to small enterprises and independent business owners its scale should be broadened and easily available ensuring effective integration (Shodmonov & Mustafakulov, 2024).

Ho: There is no significant relationship between Financial, Governmental and Staff related barriers and the implementation of sustainable management practices

H1: There is a significant relationship between Financial, Governmental and Staff related barriers and the implementation of sustainable management practices

Buhalis and Darsi claim that premium travelers are pushing hotels to adopt sustainable practices and expressing their willingness to stay in accommodations that are environmentally-friendly with high-quality services. Especially boutique hotels in Uzbekistan recognizing the importance of sustainability and have started to integrate and be a luxury, environmentally friendly hotels. To keep everything sustainable traditional techniques, recyclable construction supplies are being used in boutique hotels with the support of government initiatives which makes it realizable to achieve sustainability in the hospitality industry. There are several research results that support the view that integration of sustainability practices greatly contributes to the profitability of hotels and enhance tourist satisfaction. However, this link may not be obvious at first but it will show its profitability and viability in the long-run (Botir & Alijon, 2025).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

To measure the adoption levels and internal issues faced by the management in hotel operations to function as a sustainable establishment is the main aim of this research paper, providing a clear perspective from the hotels' point of view. The specific questions that were put forward are how effectively the hotel controls and measures energy-saving, water utilization, and waste management procedures in their day-to-day operations minimizing the harmful effects and efficiently make use of natural resources. The data that are important to be collected is measurements over statistics or observations which is why quantitative data collection method suite the best to gain appropriate information for the research gap. By getting all related data the

expected result is to be able to measure the sustainability of hotels to a certain degree and to act upon it accordingly.

3.2 Research design

The research design is descriptive as it describes the current adoption levels and internal challenges rather than explanatory or exploratory because it neither has cause and effect relationship or studying a new area of research and exploring it. The timeframe of the study is cross-sectional as the survey was gathered at one point in time from hotel subjects to see the current pattern on sustainability. The dependent variables of the survey include energy, water, and waste management; future plans for sustainability initiatives. On the other hand, the independent variables consist of financial constraints; employee knowledge on sustainability; and government regulations.

3.3 Research Method

The research applied primary data collection method through a structured questionnaire consisting question types like Likert scale, multiple choice, and multiple-response questions specifically tailored to measure current sustainability state of the hotel in terms of energy, water, waste control, similarly their local and governmental impact. Half of the data was gathered through physically going to hotels and collecting responses in-person from hotel staff and managers, and the other half was gathered by sending the link and QR codes via Google Forms to hotel employees. As the research is claimed to measure the adoption levels and internal challenges currently being applied no secondary data was used in this part of the survey. The questionnaire contains of 12 questions from the rating of hotels, applied sustainability measures to future plans contributing to it. The information gathered were processed using the Microsoft Excel, so the responses could be tabulated and descriptive statistics can be gathered.

3.4 Population and Sampling

The population of interest for this study was hotel staff mainly managers and receptionists who are familiar with hotel operations and practices. All hotels surveyed are based in Samarkand because the researcher's geographical limitation and only hotels in Samarkand being accessible.

A non-probability purposive sampling technique and convenience sampling was applied. First half of hotels were selected mainly because of accessibility and convenience and the second half were also intentionally chosen not randomly selected. The population sample was 60 respondents from 60 hotels in Samarkand. The figure was small but big enough to measure its overall current state, but not big enough to be intensive in analysis. The data was collected in 2026 from the 8th till the 15th January.

3.5 Limitations and Weaknesses of Using Method and Sampling

Some of the challenges faced in data collection and research were language issues, specifically employees not understanding the advanced English terms and vocabulary related to sustainability. That is why the questions were translated into two Russian and English languages. Another challenge was low response rate because most of the time the managers did not have time to engage and fill in responses or were not at the hotel. The use of quantitative data also had some limitations with context-poor and little room for more nuanced opinions. The absence of open-ended qualitative interviews took away some of the depth of personal experience and narrative that would have enriched the results.

The population size (60 respondents) is relatively small and because of geographical limitations it specifically focuses on hotels in Samarkand and that is why does not represent the condition of hotels in the whole country (Uzbekistan). Apart from that, the data not only does not

portray the whole country's hotels toward sustainability but also does not give the full illustration of Samarkand itself because there are more than 600 hotels situated in the region according to Booking.com. Being a non-probability and convenience sampling also poses a risk of being affected by selection bias, which would limit the generalizability of the findings.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction:

This chapter highlights the outcomes of the data done to assess the sustainability practices in Samarkand which is based on the gathered data distributed to 60 hotels and the hotel categories included are from 1 to 5 star and Boutique/Guesthouses. The majority of hotels belong to 3-star and 4-star category, respondents ranging from 18 to 23, and the least appeared hotel group is 1-2 star, with only 2 participants.

4.1 Sustainability adoption levels:

There are three main questions to find sustainability adoption levels addressing energy, water, and waste measurements. Also, the data were analyzed in SPSS and adoption index was found, which measures how many sustainability practices were implemented in the hotel on a scale of 0 to 9. In average, four of the nine proposed practices were implemented in hotels, indicated by the mean score of 4.0167. According to the frequency table about 63% of hotels have an index score of 4.00 or less, which means they have adopted 4 sustainability measures out of 9 available practices, and just 3.3% (2 out of 60) hotels demonstrate the highest index score of 9.00, indicating that a very small portion of the sample is highly sustainable.

Table 4.1

One-Sample T-Test of Total Sustainability table

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
Total_sustainability	60	4,0167	2,49400	,32197

One-Sample Test

Test Value= 0

	t	df	Sig.(2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Total_sustainability	12,475	59	<,001	4,01667	3,3724	4,6609

According the survey results in terms of energy conservation at hotels, LED lighting is undoubtedly the most widely implemented practice, which is used in 41 (36.6%) hotels. Automated lighting and Smart key-card systems are also rather common among hotels, each indicating 19.6% (22 hotels) and 25% (29 hotels). Only 9 (8%) hotels made investment on solar panels and 11 (9.8%) of the sample size reported no energy saving measures whatsoever. When the energy score was analyzed, the mean came out as M= 1.68 indicating that hotels are most likely to adopt energy saving practices more because of immediate cost reductions like LED bulbs or motion sensors (Figure 4.1):

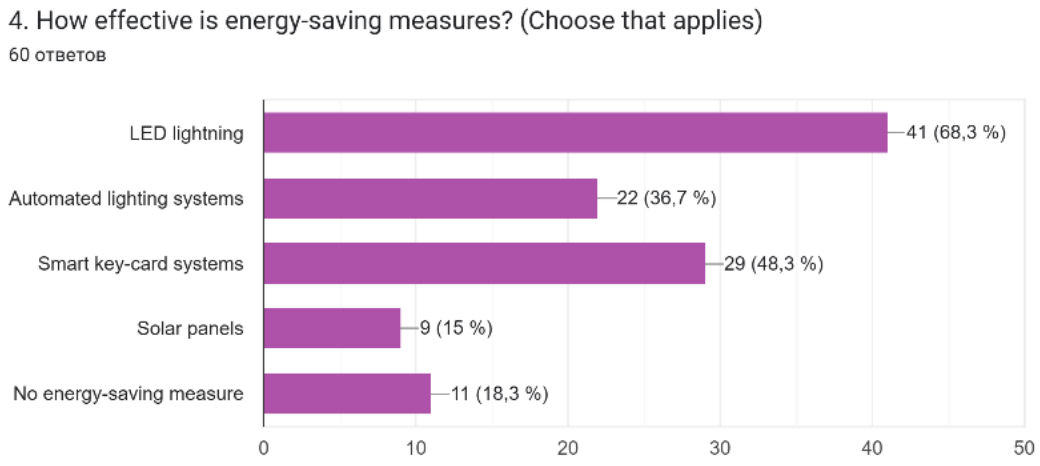


Figure 4.1: *Effectiveness of energy-saving measures in hotels (multiple-response question)*

Moreover, compared to energy measures, water-saving and waste management practices are lower. Linen and towel reuse in the category of water-saving measures is the highly implemented option with 44.3% (35 hotels), following low-flow shower and tap system showing 27.8% (22 hotels). Unfortunately, 20 hotels (25.3%), one third of the sample have no water-saving measures. And the mean is M= 0.98, with the mean below 1.0 water conservation and management measures at hotels are the weakest and they are taking no action for rational use of water resources, (Figure 4.2):

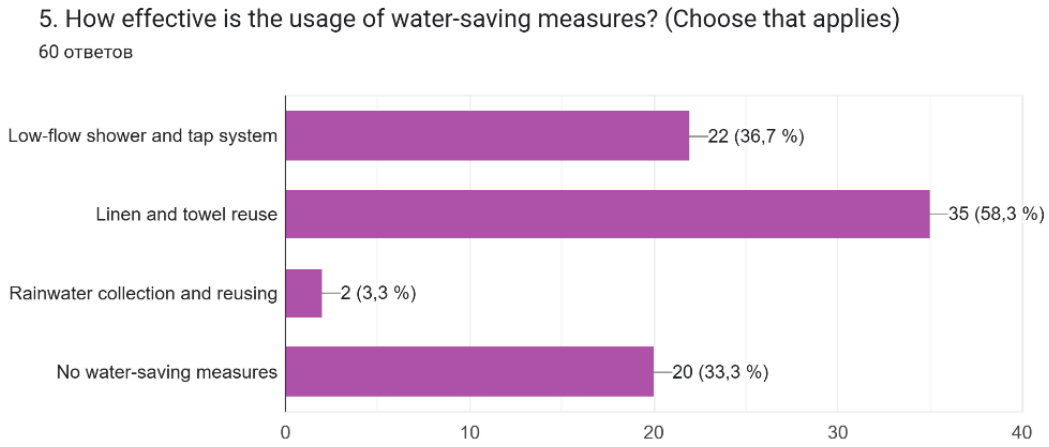


Figure 4.2: *Effectiveness of water-saving measures (multiple-response question)*

Waste management is also in one of the neglected categories, where the majority of the hotels (29) 29% are only to be seen to separate waste by plastic, paper, glass, and organic. On the other hand, 19% (19 hotels) showcased no implementation of effective waste management system.

Hypothesis N1: To test the first hypothesis of whether hotels in Samarkand have low levels of sustainability adoption rate one-sample t-test was done on SPSS. Based on the results *p* value is *<0.001* and the effect size *Cohen's d* is = 1.611 (very large effect); which means it is both statistically significant and is strong and practically meaningful. Hence, by all the gathered data it can be concluded that we accept the alternative hypothesis of Indeed hotels in Samarkand have low or moderate levels of sustainability measures and reject the null hypothesis.

Table 4.2

One-Sample T-test Effect Sizes of Total Sustainability

One-Sample Effect Sizes					
		Standardizer <a>	Point Estimate	95% Confidence Interval	
Total_sustainability				Lower	Upper
	Cohen's d	2,49400	1,611	1,223	1,992
	Hedges' correlation	2,52628	1,590	1,207	1,967

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation
Hedges' correlation uses the sample standard deviation, plus a correlation factor

4.2 Barriers to Sustainable Implementation:

The other half of the research gap is about challenges that the hotel management faces to integrate more sustainable measures, and in this case, it examines staff-related, government and financial barriers. When the data were analyzed in SPSS it showed that the mean score of staff score is 0.90 and the government score is 1.03. The mean of staff-related practices suggest that the score is very low which indicates that the sustainability measures should be regularly monitored (waste, water, energy), and if the staff is not trained properly further implementation efforts become inconsistent and inefficient.

Table 4.3

Descriptive statistics of Adoption index, Government barriers, and Staff barriers

Descriptive Statistics					
	N	Minimum	Maximum	Mean	St. Deviation
Adoption_Index	60	.00	9.00	4.0167	2.49400
Government_Barrier	60	.00	3.00	1.0333	.60971
Staff_Barriers	60	.00	3.00	.9000	.65613
Valid N (listwise)	60				

While government score is slightly higher than the staff score it still demonstrates that the current regulatory environment in Uzbekistan is in low dynamics. Hotels are just doing enough to meet the basic policy requirements but do not exceed it or do not get incentives like tax breaks, green certification, etc, to go an extra mile.

When the respondents were asked which staff related challenges mostly affect the adoption of sustainable practices 40.8% (29 hotels) responded as no training and lack of staff knowledge on sustainability, and 21.1% (15 hotels) complained about not having enough time for staff training on this matter. Moreover, in order to find out the government's part on encouraging sustainability in hotels 27% (20 hotels) and other 27% responded by weak law enforcement of environmental policies and insufficient government subsidies, and for 30% (22 hotels) on of the main concerns is lack of educational programs on sustainability.

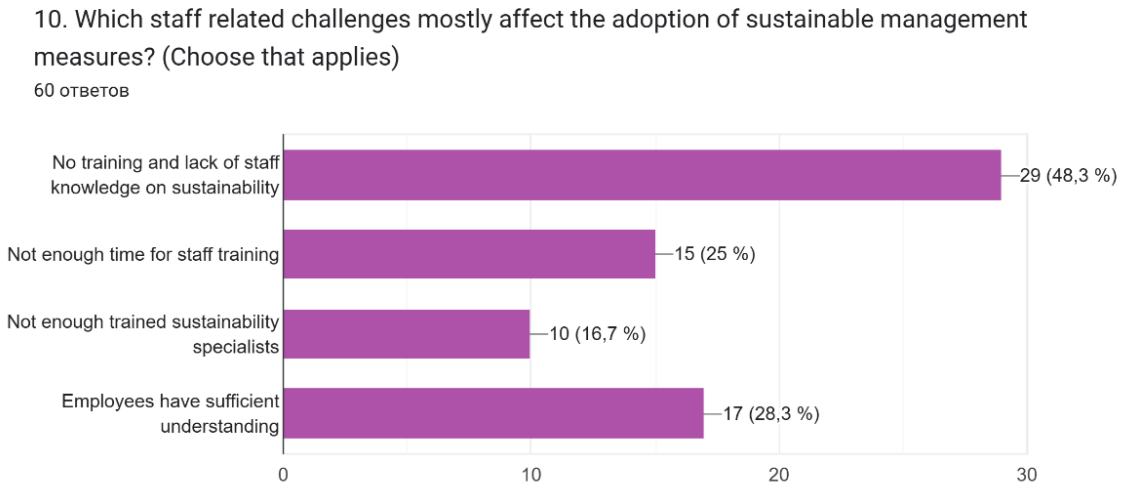


Figure 4.3: *Illustration of staff related challenges affecting the adoption of sustainable practices (multiple-response questions)*

Limited internal financial resources appeared to be the highest factor (38.3%) that hindered further implementation of sustainable practices whether it is related to installing solar panels or taking water or waste minimization measures. 31.7% reported significant initial expenses and 8.3% lack of government subsidies to be obstacles to comply with all sustainability requirements (Figure 4.4).

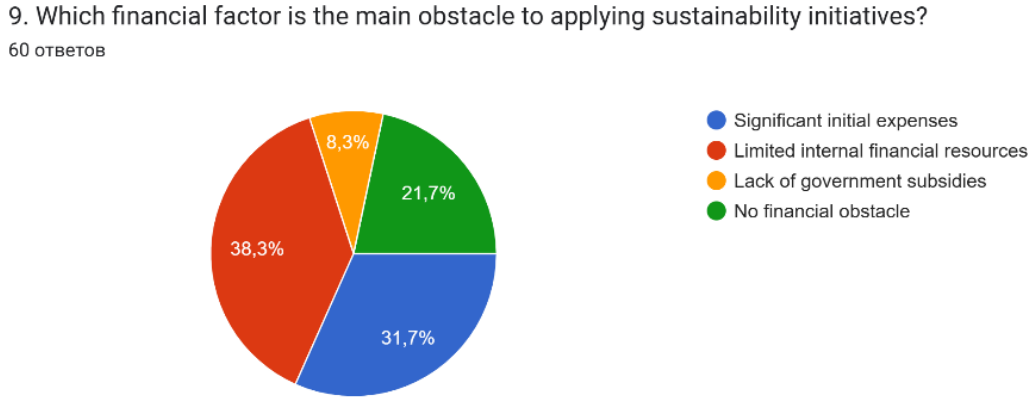


Figure 4.4: *Illustration of the main financial obstacle to sustainability initiatives*

Hypothesis N2: To test the second hypothesis Pearson correlation analysis was done to see the relationship between financial, governmental, and staff barriers and sustainability adoption initiatives. According to the results: staff barriers with sustainability came out to be weak and not statistically significant ($r = -0.040$; $p = 0.759$); government barriers with adoption ($r= 0.100$; $p = 0.447$) is weak and not statistically significant; financial barriers with sustainability is again weak and statistically not significant with $r = 0.145$; $p = 0.270$. All mentioned barriers have $p>0.05$ and therefore it does not show strong relationship towards adopting sustainability measures. Hence, the we reject the alternative hypothesis and accept null hypothesis instead (table 4.4).

Table 4.4

Correlation testing of total sustainability, staff-government-financial factors

Correlations					
		Total_sustainability	Staff_score	Government_score	Financial_factor
Total_sustainability	Pierson Correlation	1	-,040	,100	,145
	Sig.(2-tailed)		,759	,447	,270
	N	60	60	60	60
Staff_score	Pierson Correlation	-,040	1	,432**	,005
	Sig.(2-tailed)	,759		<,001	,972
	N	60	60	60	60
Government_score	Pierson Correlation	,100	,432**	1	-,259*
	Sig.(2-tailed)	,447	<,001		,046
	N	60	60	60	60
Financial_factor	Pierson Correlation	,145	,005	-,259*	1
	Sig.(2-tailed)	,270	,972	,046	
	N	60	60	60	60

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

4.3 Operational Sustainability practices:

Operational sustainability practices mainly cover areas like sustainable certification and sourcing products.

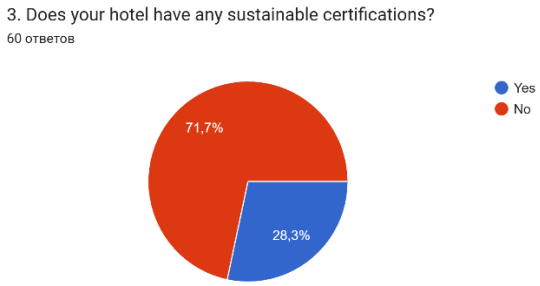


Figure 4.5: Hotel sustainability certification

According the survey results about 71.7% of hotels reported of not having any sustainability certifications, and even most of them did not know that there is one. Only 28.3% said that they have green certification, however this number most probably might be a biased response by respondent's side because many mistook green certification with hotel service certification that allows hotels to operate as one. Overall, without having formal certifications there are no clear guidelines for hotels to look up to, and this explains the reason why water-waste-energy scores are unstable and implemented random practices without having a comprehensive sustainability management framework.

To analyze their social sustainability initiatives, which is one of the core pillars of sustainability, the targeted group were asked how do they source food and other supplies to hotels. And the results were relatively positive supporting locals, indicating 55% (33 hotels) source their products locally and 45% (27 hotels) use both local and imported goods.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Overview of the study

The main aim of the study was to find out current sustainability adoption and challenges faced in hotels in Uzbekistan (Samarkand, in particular). From an environmental perspective, sustainability practices are crucial in hotels because the industry is one of the significant consumers of natural resources like energy, water, also generating lots of waste daily. Such consumption and ineffective management of resources lead to quick deterioration of them; harms the environment immensely and accelerates the process of water resources in the country. In fact, embracing sustainable practices in hotels will help to efficiently use the natural resources and minimizing its environmental footprint. From an economic point of view, by adopting sustainability measures hotels can minimize operation cost of energy, water, and waste management and benefitting in the long term despite the significant initial expenses. For these reasons, the survey was conducted to analyze the current state of hotels in Samarkand (location was chosen because of geographical limitations).

5.2 Discussion of key findings:

According to the sustainability index results, roughly, hotels adopted four out of nine proposed measures and many of them are random initiatives which does not follow any specific pattern since there is not one single guideline for them to follow. At the energy saving category, most hotels have LED lighting system and smart key-card system, water saving and waste management systems are inadequately managed without significantly beneficial measures. Based on the outcomes and analysis alternative hypothesis on hotels in Samarkand having limited/low levels of sustainability practices was accepted. Moreover, in order to identify whether financial, governmental, and staff related problems have significant relationship with low adoption rate the second hypothesis was tested and the outcome showed weak correlation between them, and hence the alternative hypothesis was rejected. One of the possible reasons why these barriers might not be strong is that hotel managers and responsible parties may not yet fully understand the importance of it and the urgent need of saving natural resources while also supporting and fulfilling their responsibility in front of the society. The same case involves people in the country, when there is demand by customers business owners would fulfill it, and because of the lack of recognizing the importance of sustainability by customers and lack of customer demand there is no significant improvement in the sense. Moreover, business owners might see adopting sustainability practicing not as a long-term cost-saving deal but rather than an expense without considerable benefits.

5.3 Implications & Recommendations

For hotel managers: Since above mention barriers does not strongly affect adoption, hotel managers should recognize that sustainability can start with simple and low-cost practices such as installing LED lighting systems, towel and linen reuse programs, waste separation, reducing single use plastics, and utilizing energy-efficient appliances; and shift their operations into more sustainable ones by gradually investing into them. In addition, sustainability gives hotels a competitive advantage among their competitors by strengthening their brand reputation and attracts environmentally-conscious customers. Even though there was a weak relationship between barriers and adoption training employees on sustainability helps effective implementation, especially in areas like waste reduction, water & energy saving, which ensures consistent compliance in daily operations. Lastly, managers should monitor to make sure everything is according their plan (tracking energy, water consumption, measure waste generation).

For tourism authorities: First and foremost, responsible authorities should create clear sustainability guidelines for hotels and other hospitality sectors and launch certification programs to encourage hotel owners to adhere to sustainability standards; and organize internal & external sustainability audits to ensure its compliance. Since many hotels lack knowledge on sustainability authorities could provide training and awareness campaigns educating about the benefits of sustainability measures and their practical implementations. Most importantly, responsible parties could provide incentives and financial support through tax reductions, grants and investments in eco-friendly technologies, which greatly motivate hotel owners.

5.4 Limitations

One of the weaknesses of this research paper is that its sample size is limited, only 60 hotels were surveyed for gathering the data. Also, it should have covered the whole country (Uzbekistan), but because of geographical limitation of the researcher it only focuses on Samarkand. In addition, responses for survey questions might be biased by participants (front desk staff, managers, owners of hotels); and some questions might be misunderstood along the way. Lastly, since the sustainability is a broad and complex concept that encompasses different environmental, social, economic aspects, the research examined only key dimensions and limited an in-depth analysis of each sustainability components.

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Appendices

Appendix A: Main Questionnaire

1. What category does your hotel fall under?
5 star
4 star
3 star
1-2 star
Boutique/Guesthouse
2. How informed is the hotel management about sustainable management practices?
Very informed
Moderately informed
Not informed
3. Does your hotel have any sustainability certifications?
Yes
No
4. How effective is energy-saving measures? (multiple-response question)
Led lightning
Automated lighting systems
Smart key-card systems
Solar panels
No energy-saving measures
5. How effective is the usage of water-saving measures? (multiple-response question)
Low-flow shower and tap system
Linen and towel reuse
Rainwater collection and reusing
No water-saving measures
6. How effectively implemented waste management measures? (multiple-response question)
Waste is separation by plastic, paper, glass, organic
Minimization of single-use plastics
Organic waste recycling
No waste management system
7. How do you source food, beverages and other products for the hotel?
Mostly locally sourced
Both local and imported
Mostly imported products
8. How does the management assesses the sustainable performance of the hotel?
Perform internal audits
External inspections
Feedback from visitors on sustainability
The environmental performance is not evaluated
9. Which financial factor is the main obstacle to applying sustainability initiatives?
Significant initial expenses
Limited internal financial resources
Lack of government subsidies
No financial obstacle

10. Which staff related challenges mostly affect the adoption of sustainable management measures? (multiple-response question)
11. What are the major difficulties to develop sustainability in terms of government regulations and incentives? (multiple-response question)
Weak law enforcement of environmental policies
Insufficient government subsidies
Lack of educational programs on sustainability
Efficient governmental assistance
What is your main sustainability plan for your hotel in the future?
Low-energy equipment
Water-saving systems
Waste minimization and recycling
Employee trainings programs
No plans for investing in sustainability programs

Appendix B: Analysis results for hypothesis 1 **Table 4.2**

One-Sample T-test Effect Sizes of Total Sustainability

One-Sample Effect Sizes					
Total_sustainability		Standardizer <a>	Point Estimate	95% Confidence Interval Lower	Upper
	Cohen's d	2,49400	1,611	1,223	1,992
	Hedges' correlation	2,52628	1,590	1,207	1,967

a. The denominator used in estimating the effect sizes.
Cohen's d uses the sample standard deviation
Hedges' correlation uses the sample standard deviation, plus a correlation factor

Appendix C: Analysis results for hypothesis 2 **Table 4.4**

Correlation testing of total sustainability, staff-government-financial factors

Correlations					
		Total_sustainability	Staff_score	Government_score	Financial_factor
Total_sustainability	Pierson Correlation	1	-,040	,100	,145
	Sig.(2-tailed)		,759	,447	,270
	N	60	60	60	60
Staff_score	Pierson Correlation	-,040	1	,432**	,005
	Sig.(2-tailed)	,759		<,001	,972
	N	60	60	60	60
Government_score	Pierson Correlation	,100	,432**	1	-,259*
	Sig.(2-tailed)	,447	<,001		,046
	N	60	60	60	60
Financial_factor	Pierson Correlation	,145	,005	-,259*	1
	Sig.(2-tailed)	,270	,972	,046	
	N	60	60	60	60

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

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International Scientific Journal
Science and Innovation Series A
Volume 5 Issue 4

ISSN: 2181-3337

Published: 30.04.2026. Font: “Times New Roman”.

LLC “Science and innovation”
License Mass Media №:1597 27.04.2022
License Publisher №:455168 21.11.2024
Address: 100121, Uzbekistan, Tashkent city, Yakkasaroy district,
Shota Rustaveli Street 150, Vega Business Center, 6th floor, Room 2.
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