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RESEARCH ON MODELING APPLICATION OF ORDINARY DIFFERENTIAL EQUATIONS TO PRACTICAL PROBLEMS AND CASE-ORIENTED TEACHING

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Abstract. *Ordinary differential equation is an important component of higher mathematics, and its modeling method is widely applied to solving various practical problems. Traditional teaching of ordinary differential equation lays particular emphasis on theoretical deduction, which makes it difficult for students to perceive the application value of mathematical knowledge. In this paper, the case-based teaching method is adopted, and three typical practical problems including solution dilution, identification of painting and calligraphy counterfeits and computer virus propagation are selected. The corresponding ordinary differential equation models are established and solved respectively, with the internal laws and mathematical principles of each problem analyzed. Through the modeling and solution of multi-field cases, the advantages of ordinary differential equations in depicting natural phenomena and practical problems are demonstrated, and the teaching concept of integrating theory with practice is reflected. Practice has proved that case-based teaching can effectively reduce the learning difficulty of ordinary differential equations, stimulate students' learning interest, help students grasp the idea of mathematical modeling and improve their ability of knowledge application, which plays a positive role in improving the teaching effect of the ordinary differential equation course.*

Keywords: *ordinary differential equation; mathematical modeling; case-based teaching; practical application; model solution.*

1 Introduction

As one of the core branches of higher mathematics, ordinary differential equations have distinctive characteristics in the field of mathematical modeling, and serve as an important bridge connecting mathematical theories with practical problems. Case-based teaching is a highly targeted teaching mode in the course of ordinary differential equations, which can vividly interpret the teaching concept of integrating theory with practice [1]. The traditional teaching mode mostly follows a fixed process of "theorem elaboration - proof and deduction - example explanation". Tedious theoretical deductions often occupy the core time of classroom teaching, leading to students' distraction and a significant decline in the efficiency of knowledge acquisition in the subsequent example explanation session. Therefore, how to effectively attract students' attention and continuously stimulate their learning interest has become a key issue to improve the teaching quality of the ordinary differential equation course.

Case-based teaching can exactly make up for this deficiency. This teaching mode abandons tedious pure theoretical indoctrination, evokes students' resonance through concrete practical problems, and is more conducive to focusing students' attention [2]. Among all branches of higher mathematics, ordinary differential equations are particularly suitable for case-based teaching due to their distinctive characteristics of wide application scenarios and close integration of theory with

practice. Carrying out teaching with specific cases can not only help students achieve an in-depth integration of theory and practice, but also make the abstract basic theories of ordinary differential equations intuitive and perceptible, thereby improving students' ability to analyze and solve problems and strengthening their abstract thinking literacy [3-6]. The following part will combine specific cases to explore the teaching approaches of theoretical knowledge of ordinary differential equations under the case-based teaching mode.

2 The Modeling and Application Examples of Ordinary Differential Equations in Practical Problems

2.1 Modeling and Solution of Ordinary Differential Equation for the Solution Dilution Problem

Case 1: Consider a salt solution with a salt concentration of 0.3 kg/L. This salt solution is poured into a container holding 10 L of pure water at a constant flow rate of 2 L/min. After the solution in the container is fully stirred and diluted, it flows out at a rate of 2 L/min. The question is: what is the mass of salt remaining in the container after 5 minutes?

Analysis: The core of this problem is to embody the idea of mathematical modeling, that is, to extract key data from specific practical problems, construct a suitable mathematical model and solve it. Among the model systems of various branches of mathematics, ordinary differential equation models are widely applied, which can accurately depict the variation laws of numerous natural phenomena in real life. Therefore, for this problem, we can adopt the thinking of ordinary differential equation modeling, and finally obtain the answer to the problem by establishing the corresponding ordinary differential equation model and solving its particular solution.

Solution: Let time t be the independent variable, and let the mass of salt in the container at time t minutes after injection be the unknown function $y(t)$ to be solved. Take an arbitrary time interval $[t, t+\mathrm{V}t]$, then the variation of the mass of salt in the container over this time interval is

$$y(t+\mathrm{V}t)-y(t)\approx 0.3\cdot 2\mathrm{V}t-\frac{y(t)}{10}\cdot 2\mathrm{V}t.$$

Divide both sides by $\mathrm{V}t$, and let $\mathrm{V}t\to 0$, then we obtain the initial value problem

$$\begin{cases}\dfrac{dy}{dt}=0.6-0.2y(t)\\ y(0)=0\end{cases} \qquad (1)$$

The solution of equation (1) is

$$y(t)=3-3e^{-0.2t}.$$

Therefore, when t=5, the mass of salt remaining in the container is

$$y(5)=3-3e^{-0.2\times 5}\approx 1.9 \text{ kg}.$$

This example fully embodies the core idea of mathematical modeling. Taking the salt solution dilution problem as a carrier, a time variable is introduced to construct an ordinary differential equation model. In the process of explaining this example, students can not only truly understand the ideas and methods of mathematical modeling and experience the pleasure of constructing mathematical models to solve practical problems, but also fully demonstrate the inherent beauty and application value of mathematics.

2.2 Construction and Application of Radioactive Decay Model for Identification of Painting and Calligraphy Counterfeits

Case 2: In the process of human cultural development, the works of renowned painters and calligraphers are often targeted for forgery due to their dual artistic and collection values. Therefore, the authenticity identification of paintings and calligraphy has always been an important subject in the fields of cultural inheritance and art collection. At present, the identification of such works mostly relies on manual judgment by experts with years of experience, and this method has obvious limitations and risks — some works initially identified as authentic by experts are subsequently proven to be counterfeits. Based on this, we cannot help but ponder: can we start from a mathematical perspective and apply rational thinking and quantitative analysis methods to provide a brand-new technical approach and support for the identification of ancient paintings and calligraphy?

Analysis: Before constructing the mathematical model, it is necessary to clarify the characteristics of raw material components for the creation of paintings and calligraphy. Artists often adopt mineral substances as pigments in their creation, and some minerals such as radium and lead are radioactive. According to the definition in physics, radioactivity refers to a phenomenon in which the atomic nuclei of certain elements undergo fission and release microscopic particles, leading to a decrease in the number of protons in the atoms and their eventual transformation into other elements, among which lead is a typical radioactive element. Based on this characteristic, if we can deduce the variation law of lead content $M(t)$ with time t during the decay process, and then obtain the actual lead content in the painting and calligraphy works through detection, we can calculate the actual age of the works, and further judge whether they are modern imitations.

Solution: According to the principles of physics, the decay rate of lead is proportional to the mass M of undecayed lead atoms at that time. Set the initial condition: the mass of lead is $M_{t_0} = M_0$ when time $t = t_0$. The decay rate of lead can be expressed as the derivative $\frac{dM}{dt}$ of mass M with respect to time t. Since the mass decreases with time during the decay process and the decay rate is a negative value, a mathematical model C

$$\begin{cases} \dfrac{\mathrm{d}M}{\mathrm{d}t} = -kM \\ M(t_0) = M_0 \end{cases} \qquad (2)$$

can be established accordingly, where k (k>0) is a constant, referred to as the decay coefficient.

Solving equation (2), we obtain

$M = M_0 \mathrm{e}^{-k(t-t_0)}$.

This law not only depicts the decay characteristics of lead, but also represents the common decay law shared by most radioactive elements. It can be inferred that the content of lead shows an exponential decreasing trend with the passage of time t. Based on this, we can calculate the survival age of a painting and calligraphy work by detecting its actual lead content. It should be clarified that if the age calculated by this method is inconsistent with the claimed creation age of the work, the work can be judged as a counterfeit. Even if the calculated age is consistent with the claimed age, it cannot directly prove that the work is authentic — because this model can only quantify the survival time of the work, and is unable to judge the core authenticity attributes such as the authorship of the work.

This example constructs an ordinary differential equation model based on the decay law of radioactive elements — a model that falls into the category of the most basic separable variable differential equation models. By solving this model, we can derive the functional relationship between lead content and time. Further, combining with the actual detected lead content in paintings and calligraphy works, we can calculate the actual survival age of a "famous painting" and ultimately judge whether it is a counterfeit. This is a typical case of integrating theory with practice, which enables students to intuitively understand the application value of ordinary differential equations in solving practical authenticity identification problems and deeply realize the practical significance of mathematical modeling.

2.3 Analysis and Exploration of the Differential Equation Model for Computer Virus Propagation

Case 3: Computer viruses have become a prominent concern in the current field of computer science. Their propagation poses a severe threat to the security of computer systems and the internet ecosystem, and has thus become a key focus of cybersecurity governance for all countries. With the rapid popularization of the internet, computer viruses have gained a more convenient propagation environment: their types are increasing steadily, and their transmission capabilities are continuously enhanced, inflicting severe damage on computer system resources. The propagation process of computer viruses is complex, subject to the constraints and influences of multiple factors. This paper attempts to construct a mathematical model for computer virus propagation based on differential equations, and further analyze the propagation laws and evolutionary characteristics of viruses by virtue of this model.

Analysis: First, the propagation characteristics of computer viruses are briefly explained: their propagation process is highly similar to the transmission mechanism of infectious diseases in the field of biology. In a network environment, if an executable program is infected by a virus and invades a certain computer system, the virus will spread on a large scale within the system once the infected program is run. In view of the characteristics of computer viruses with fast propagation speed and wide influence range, to simplify the process of model construction and facilitate the analysis of core laws, the following assumptions are made for the problem of computer virus propagation:

(1) In the network system, the system files infected by the virus have immunity and will not be infected by the same virus again.

(2) The incubation period of viruses is ignored in the process of model construction, that is, the time-delay effect of virus propagation is not taken into account.

Based on the above assumptions, the executable programs in the network system can be divided into three categories: the first category refers to the susceptible programs that have not been infected by viruses yet, and their quantity is denoted as $S(t)$; the second category refers to the programs that have been infected by computer viruses, and their quantity is denoted as $I(t)$; the third category refers to the programs that have obtained immunity and will no longer be infected by the virus after being treated by antivirus software and other methods due to virus infection, and their quantity is denoted as $R(t)$.

Solution: Assume that the total number of executable programs in the network system remains constant during the propagation of computer viruses, denoted as a constant N, i.e., it satisfies

$$S(t)+I(t)+R(t)=N.$$

Let α be the infection rate of the computer virus and β be the recovery rate, then the system of differential equations can be obtained as

$$\begin{cases} \frac{dS}{dt} = -\alpha SI \\ \frac{dI}{dt} = \alpha SI - \beta I \\ \frac{dR}{dt} = \beta I \end{cases},$$

from

$$\frac{dS}{dt} = -\alpha SI, \frac{dI}{dt} = \alpha SI - \beta I,$$

we obtain

$$\frac{dI}{dS} = \frac{\alpha SI - \beta I}{-\alpha SI},$$

i.e.

$$\frac{dI}{dS} = -1 + \frac{\beta}{\alpha S}.$$

This is a simple separable variable equation, and its solution is

$$I(S) = -S + \frac{\beta}{\alpha}\ln S + C,$$

Let the initial condition be $I(t_0) = I_0$ and $S(t_0) = S_0$ for $t = t_0$, and denote $\rho = \frac{\beta}{\alpha}$. Substituting into the above equation, we obtain the constant $C = I_0 + S_0 - \rho \ln S_0$, and finally the particular solution of the equation satisfying the initial condition is

$$I(S) = I_0 + S_0 - S + \rho \ln \frac{S}{S_0},$$

$\rho = \frac{\beta}{\alpha}$ is referred to as the threshold value. Analysis shows that the computer virus will spread if $S_0 > \rho$, i.e., the number of executable programs not yet infected by the virus exceeds the threshold value.

The model constructed above is only a basic simplified model for computer virus propagation. In actual network environments, the virus propagation process is far more complex. On the one hand, people will actively take prevention and control measures such as deploying network firewalls and updating virus databases in real time to intervene in virus propagation. On the other hand, this model does not take into account the virus incubation period — in reality, a system infected with a virus usually does not malfunction immediately; instead, there is a time interval from infection to the onset of failures, which means that virus propagation has a time-delay effect. Therefore, a virus propagation model for real network scenarios needs to take into account complex factors such as prevention and control interventions and time delays, and its construction is far more difficult than that of the simplified model. Generally, it is necessary to

establish a complex delay differential equation model to accurately depict the actual propagation process.

3 Conclusions

This paper discusses several application cases of the case-based teaching method in the differential equations course. The aforementioned cases cover a variety of disciplinary fields such as humanities and arts, and computer science. Introducing and explaining these cases in the teaching of ordinary differential equations enables students to intuitively perceive the application value and immense charm of ordinary differential equations, thereby effectively enhancing their interest in learning this course. It can be seen that the case-based teaching method is different from the traditional conventional teaching mode. Its advantage lies in the ability to help students firmly grasp the core theoretical knowledge of ordinary differential equations while infiltrating relevant knowledge from other fields. This puts forward higher requirements for teachers: it is necessary to continuously delve deep into teaching content, extensively explore specific cases in daily life and various disciplinary fields, and organically integrate these cases into the teaching process. In this way, students can truly experience the unique charm and practical value of ordinary differential equations, so as to improve the teaching effect.

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MODELING AS THE MAIN WAY OF COGNITION

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Abstract. *This article examines modeling as one of the main and most effective ways of cognition. Modeling enables the representation of complex objects, processes, and phenomena in a simplified and structured form, which facilitates deeper understanding, analysis, and prediction. The paper discusses the theoretical foundations of modeling and highlights its significance in scientific research, education, technology, and social sciences. Various types of models and their role in the cognitive process are analyzed, demonstrating how modeling contributes to the development of systematic thinking and knowledge acquisition.*

Keywords: *modeling, cognition, cognitive process, scientific research, model, abstraction, systems approach.*

Introduction

Modeling is currently attracting close attention and has received unusually wide application in many fields of knowledge: from philosophical and other humanitarian branches of knowledge to nuclear physics and other branches of physics, from problems of radio engineering and electrical engineering to problems of mechanics, physiology and biology, etc. It has become:

a) a general scientific, highly effective tool of cognition,

b) the method of forecasting engineering and design developments;

c) the method of machine simulation of long-term programs and plans in the field of economics, analysis and evaluation of various options for responsible decisions and the consequences of their implementation.

“A model is understood as a mentally imagined or materially realized system that displays and reproduces an object in such a way that its study provides new information about this object.” [2].

A model is a system, the study of which serves as a means to obtain information about another system. [1].

Modeling is the main way we learn about ourselves and the world around us. Defining the epistemological role of modeling, we note the variety of models in science and technology. The object being modeled is called the original, and the modeler is called the model. Models are classified based on the most significant features of objects. These signs are:

1) the law of functioning and the characteristic features of expressing the properties and relationships of the original;

2) the grounds for converting the properties and relationships of the model into the properties and relationships of the original.

Models can be divided according to the first feature into logical (according to the laws of logic in human consciousness) and material (according to the objective laws of nature) models. In turn, logical models are divided into figurative symbolic and figurative-symbolic (mixed) models. Material models are divided into functional, geometric, and functional–geometric models. Functional and functional-geometric models, depending on the original, are divided into physical

and formal ones. According to the second feature, conditional (based on basic conditions or agreements), analog (based on basic conclusions by analogy, continuous) and mathematical (mathematical methods of expression) models are distinguished.

Mathematical models can be distinguished from computational ones (mathematical representation of formulas, graphs, algorithms, etc.) and corresponding models (mathematical dependencies). Similar models are distinguished from the corresponding ones (proportionality of variables to the corresponding variables of the original). Such models can be logical and material. Such material models are divided into analog (continuous), digital (discrete), and analog-to-digital (combined and hybrid) models.

In general, the modeling process consists of the following steps::

1. Setting the task and determining the properties of the original to be investigated.

2 A statement of the difficulty or impossibility of researching the original in kind.

3. The choice of a model that captures the essential properties of the original well enough and is easily amenable to research.

4. Study the model in accordance with the task.

5 Transfer of the results of the model research to the original.

6 Checking these results.

The main tasks are: firstly, the selection of models and secondly, the transfer of the results of the model research to the original. Historical development of modeling. Historically, the first models as substitutes for some objects were undoubtedly symbolic conditional models. Or there were linguistic signs that naturally arose in the course of human development and gradually formed a spoken language.

The next stage in the development of modeling can be considered the emergence of symbolic numerical designations. Information about the results of the account was initially preserved in the form of notches. The gradual improvement of this method has led to the representation of numbers in the form of digits as a system of signs. It can be assumed that the notches were the prototype of the Roman numerals I, II, III, V, X.

The further development of sign models is associated with the emergence of writing mathematical symbols. The most ancient written texts currently known date back to about 2000 BC (Egypt and Babylon). There is reason to believe that the Babylonians already used the concept of the similarity of right triangles. Modeling was significantly developed in ancient Greece in the V-III centuries BC. A geometric model of the solar system was created, the physician Hippocrates used his physical analogous model, the bull's eye, to study the human eye, and the mathematician Euclid created the doctrine of geometric similarity. As mechanical production, shipbuilding, urban planning, etc. develop and strengthen, it is increasingly found that the geometric similarity of physically homogeneous objects is insufficient to predict the properties of large objects based on the properties of smaller objects.

The first step in the development of the theory of similarity in physical modeling was made by I. Newton (1643-1727), who formulated the condition for the similarity of mechanical phenomena. Further development took place for a long time by defining particular similarity conditions for phenomena of only a certain physical nature – the work of I.P.Kulibin (1735-1818) and L. Euler (1707-1783) in the field of structural mechanics, V.L.Kirpichev (1845-1913) in the field of elasticity, etc. Finally, in 1909-1914, N.E.Zhukovsky, D.Releyev, and F. Buckingham formulated a theorem that allowed them to establish conditions for the similarity of phenomena of physical nature.

In parallel, there was the development of logical modeling in a symbolic form, primarily the development of mathematics. At the end of the 16th century, D. Neper (1550-1617) invented logarithms. At the end of the 17th century, I. Newton and G. Leibniz (1646-1716) created differential calculus. Numerical methods for solving various problems are being developed. The first computing devices include the abacus (XV-XVI c.), the slide rule (early XVII c.). For a long time, computing devices were exclusively mechanical – an arithmometer, calculating and solving mechanisms, etc. And only in the 30s of our century (XX century.) begins the development of electronic analog and digital computing devices.

And the first generalizations of two directions of material modeling:

a) physical;

b) formal calculations using computing devices were made by V.A. Venikov (1949) and L.I. Gutenmacher (1949), and then further developed by I.M.Petelbaum (1959), A.M.Suchilin (1964), A.M.Alabuzhev (1968). Philosophical concepts of the main issues of modeling are reflected V.A.Stoff, I.B.Novikov, N.A.Uemov, and others.

The main aspect is not learning the rules, but the process of thinking itself. The student chooses the behavior strategy of the model himself (for example, the short task condition is a model of a text task), tries to find out what will happen as a result of his actions (solving the problem), based on his experience, draws a conclusion about the significance of the results obtained (the answer to the problem). It is well known that the language of information and logical models is universal, so mastering it makes the learning process of mathematics more meaningful.

The technology of teaching information modeling can be based on the method of active reflection. This method determines both the main learners of learning (teacher-student) by implementing a personality-oriented model currently being developed in a number of psychological, pedagogical and methodological studies, as well as the sequence of informing operations, explaining prescriptions, setting tasks and executing computer technologies to solve it.

The method of active reflection involves the activation of the student's mental and creative activity and the expansion of independence of choice in the process of teaching mathematics. In almost all sciences, the construction and execution of models is a powerful tool of cognition. When solving any problem, the main role is played by experiment and model, as well as analysis of the results obtained. The model provides a correctly set experiment by refining the model. The experiment has two directions: processing the results and planning the experiment.

The reliability of the model is achieved through observation and logically correct data processing. When building a model, a problem arises – the importance and role of the teacher in this process. The solution to this problem involves the use of a number of methodological models that define the general activities of a mathematics teacher.

1. Using concrete examples from world culture, the value of mathematical knowledge should be shown and revealed.

2. The use of science in society should be a means of connecting mathematical science with universal culture in the process of teaching mathematics.

3. In order for students to understand the cultural and therefore personal value of mathematical education, the content of the course must undergo significant changes.

4. The implementation of a holistic approach in teaching mathematics involves the construction of an optimal course option.

5. Teacher-student dialogue The mathematics issues under consideration are discussed on equal terms and are worked out in principle. A unified position reflecting the modern interpretation of the issue.

6. The dialogue that the student conducts with himself. It is born in the course of emotional perception and awareness of mathematical facts.

People tend to explore the world on models. When starting to study a scientific discipline (mathematics), we first get acquainted with the system of assumptions adopted for this discipline: which properties or connections of the studied objects and phenomena are essential for this discipline, and which are not.

When building any model, we always sacrifice something, refuse (abstract) from considering something that is not essential for the purposes of this model. The highest form of abstraction is mathematical abstraction. It allows you to forget about the nature of the modeled objects and connections during logical reasoning. All mathematical objects have the same logical nature. They are connected by logical connections and interact according to the rules of mathematics. This allows us to introduce a uniform universal formalization system for studying different processes and phenomena.

We will give the basic definitions and concepts for formalizing the model of the subject of mathematics. The information method is the result of the interaction of data and information methods, considered in the context of this interaction. The most important, from the point of view of management, are the following six properties of information: objectivity, completeness, reliability, adequacy, relevance, accessibility. Modeling is an information method consisting in the logical closure of an open system in order to limit the number of its possible states and the relationships between its elements in order to consider them exhaustively.

Model. The concept of the word "Model".

1. A model is a sample of a product, as well as a sample for making something.

2. Reduced reproduction of something.

3. Type and brand of construction.

Since we have compared management with science, it is necessary to recall such a widespread and effective scientific method as modeling. A model is a system specially designed for research that reflects the basic properties of the object under study. It recreates the real situation in an artificial way for studying.

The word "model" comes from Latin. Modus is a copy, a sample, an outline. These are, for example, geographical maps, diagrams of mechanisms and electronic devices, structural formulas in chemistry, etc. In general, any simulation system that replaces the object under study and facilitates the search for solutions to scientific, technical, economic or any other problem can be considered a model. The model usually simplifies, coarsens the real object, frees it from minor details that only obscure the essence of the matter.

People have long used models to study real objects and phenomena. In ancient times, for example, future irrigation facilities were imitated in this way. If the model differs from the original only in size, and the processes occurring in them are of the same nature, then such modeling is called physical, a scaled–down copy of an airplane in a wind tunnel, dam or bridge in an artificial water stream are examples of such models. When modeling is carried out using a process of a different nature, it is a method of analogy. Thus, the flow of liquid through complex hydraulic structures can be replaced by electric current in a specially assembled conductor circuit, and vice versa, the behavior of electrical circuits is sometimes studied using a hydraulic model. This type

of research has become widespread, and the special devices used in them are called analog devices, which include analog computers.

But perhaps we are most interested in a different type of modeling, when a set of mathematical expressions describe the behavior of the object under study. Such models make it possible to identify the most significant relationships and dependencies between the elements in the system under study, and help to understand the various aspects of the problem to be solved. We are talking about an accurate description of the most diverse processes and phenomena that one has to deal with in all areas of human activity. Considering the possible solutions on paper, it is relatively easy to choose the optimal one. No wonder they say that many discoveries were born on the tip of a pen. However, we have mentioned more about paper here for the sake of a red word, since you cannot sort out many options "manually", and some complex mathematical dependencies on paper turn out to be intractable. But now we have computers, and they can solve almost any equation.

The main value of mathematical models is that they allow you to create artificial realities and predict the consequences of certain actions or events, and this is very important, in particular, for production planning and management. By resorting to modeling, we are waiting for a reasonable answer to the question: what happens if we act one way or another?

The use of models as substitutes for the studied real phenomena is now one of the main signs of a scientific approach both in cognition of reality and in practical activity. A characteristic feature of this method, as we have already noted, is that at a certain stage of cognition, instead of a real phenomenon, we consider its idealized model, which we explore. But such a replacement is advisable only if the model correctly reflects the properties of the studied reality from the side we are interested in and at the same time is simpler and more convenient for research than the simulated real object. And just in connection with the expansion of the scope of computers, the role and importance of mathematical models for representing real objects and situations have now increased.

Over the millennia of its existence, mathematics has come a long and difficult way, turning from a primitive ability to count into a vast and extensive scientific branch. People appreciated the importance of mathematics in ancient times, realizing that this science provides not only computational methods, but also serves as a universal key to penetrate into the essence of the fundamental laws of reality being studied.

Mathematics has chosen its own language – very precise, economical and at the same time universal, which has proved effective in a wide variety of fields of knowledge. Mathematical symbols make information recording compact and convenient for subsequent processing. Mathematics introduces the concepts of quantity, precision, clarity, and evidence into any field. Most applied sciences now "speak" mathematical language.

Always occupying the most honorable place among the sciences, mathematics, until recently, found limited use in solving economic problems. It is only with the advent of computers that mathematics becomes an everyday working tool for planners, economists, engineers, agronomists, livestock technicians, and other professionals involved in the field of material production.

Highly qualified mathematicians at institutes, using the latest scientific achievements, develop a mathematical model for solving a specific practical problem, after that they create a modeling algorithm and a standard computer program with which any practitioner can solve the same problem for his household. He does not need to thoroughly know the equations that form a

mathematical model, nor the methods for solving them. What he has to do is insert a program into the computer and enter into it the necessary data about the actual production conditions.

Conclusion: In conclusion, modeling plays a crucial role in cognition as a universal and efficient method of understanding reality. It allows complex phenomena to be perceived, analyzed, and interpreted through simplified representations. The use of modeling enhances cognitive activity, supports scientific inquiry, and improves problem-solving across various fields. Therefore, the effective application of modeling significantly contributes to the advancement of knowledge and the accuracy of scientific outcomes.

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CONVERTING SOLAR ENERGY INTO ELECTRICITY

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Abstract. *This article extensively covers the physical and technological foundations of the process of converting solar energy into electricity. The properties of solar radiation, the mechanism of the photoelectric effect, and the structure and principles of operation of solar panels based on semiconductor materials are analyzed. The efficiency, advantages and disadvantages of monocrystalline, polycrystalline, and thin-film solar panels are also comparatively considered. The article also highlights the importance of integrating solar energy into power grids, inverters, and energy storage systems, and evaluates the future prospects of renewable energy sources on a scientific basis.*

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

Introduction: Today, the global energy system is facing serious challenges. The limited availability of traditional fuel sources, environmental pollution, and climate change are sharply increasing the need for alternative energy sources. Among them, solar energy is considered one of the most promising and environmentally friendly energy sources. The process of converting solar energy into electrical energy is a complex technological system based on the achievements of modern physics, materials science, and electrical engineering.

Solar energy is the energy of electromagnetic radiation generated as a result of thermonuclear reactions occurring in the core of the Sun. Sunlight reaching the Earth consists of a stream of photons, and when these photons interact with matter, energy is transferred. It is this phenomenon that forms the basis of the principle of operation of solar cells.

The conversion of solar energy into electrical energy is based on the photoelectric effect. This phenomenon was first discovered in 1839 by A. E. Becquerel and is explained by the formation of electric charge carriers in certain materials under the influence of light. Modern solar panels are mainly made of semiconductor materials, in particular silicon.

In the structure of the silicon atom, p-type and n-type layers are formed. When sunlight falls on it, photons eject electrons from the valence band to the conduction band. As a result, under the influence of an electric field, electrons and holes move in opposite directions, creating an electric current.

Solar panels are technologically divided into several types:

- Monocrystalline solar panels- Have a single crystal structure and are characterized by high efficiency (20–24%). They are complex and expensive to manufacture.
- Polycrystalline solar panels- Consist of several crystals and have a relatively low efficiency (15–18%), but are widely used due to their low cost.
- Thin-film panels- Made on the basis of cadmium telluride or amorphous silicon. Although they are lightweight and flexible, they are less efficient.

Electricity is undoubtedly the most convenient form of energy to use. From high school physics, the concepts of electric charges, electric current and the associated electric field, potential, electromotive force, current strength, current density, thermal, chemical, and magnetic effects of current are known. We assume that the student also has basic knowledge about the structure of the atom and the structure of the atomic nucleus. In practice, people often work with solids, and the issues we are going to describe are directly related to the properties of such bodies. Therefore, let's first briefly get acquainted with the structure of solids.

First, let's recall the structure of the atom. As is known, its planets revolve around the sun in certain orbits. Similarly, around the positively charged nucleus of an atom (which has a very small volume, almost the entire mass of the atom), negatively charged light particles - electrons - revolve in certain orbits, separated from each other. This is a planetary imitation of an atom, in which there are many orbits for its electrons, and they are in equilibrium in states close to the nucleus, but possible states far from the nucleus, where there are no electrons, remain empty. An atom absorbs light energy in the form of certain small fractions, particles called photons (photon - a particle of light).

When a photon is absorbed, an electron in the atom goes to a higher energy state, and vice versa, when an excited electron goes to a lower state, the atom emits a photon of light energy. Depicting the energy states of electrons in an atom on the E energy axis greatly simplifies considerations. It is customary to call the state of the electron in the atom closest to the nucleus the E_1 level, and the subsequent ones the E_2, E_3, . . . En levels. An electron in the E_1 level can move to the E_2, E_3, and En levels due to the photon energy absorbed by the atom. However, for this, the photon energy must be equal to the difference in energy levels.

Let us recall one rule - the Pauli exclusion principle. According to it, at most two electrons with opposite spins (direction of velocities) can be in one energy level, but there can be one electron in the level or the level can be without electrons (empty). This depends on the composition of the atom of the chemical element. An electron cannot have energy values between the levels, these intervals are forbidden energy intervals.

A solid consists of a large number of atoms. In this case, it is natural to ask what the energy states (levels) of electrons will be. According to the above-mentioned Pauli exclusion principle, instead of the energy level of an electron of an atom, there should be states in a solid in which the electrons of all atoms can occupy. The number of these states should be as many as the number of atoms that make up the solid. These states constitute the range (zone) of allowed energies. It is not difficult to notice that the forbidden energy bands are empty among the allowed energies.

The extent to which these allowed bands are filled with electrons depends on the chemical element to which the atoms belong and, consequently, on how many electrons are in the atom, and on some other factors. Depending on this, substances are divided into groups such as metals, semiconductors, dielectrics. In metallic substances that conduct electricity well, only half of the upper allowed band is filled with electrons, they are called free electrons and they can participate in the conduction of current.

In semiconductors, at a temperature of absolute zero (K), the upper allowed energy band is completely occupied by electrons, but there are no electrons in the band above it. The electrons in the fully filled band are bound, unbound electrons, and cannot participate in current conduction. At this temperature, the semiconductor does not conduct current (insulator-dielectric). However, at any temperature above absolute zero, some of the electrons in the filled band can move to the upper band, that is, the bound electrons turn into free electrons (conduction electrons). The

semiconductor conducts current to a certain extent. This phenomenon is similar to the transformation of liquid molecules into vapor molecules.

- The zone of electrons in the bond is called the valence band, and the zone of free (conduction) electrons is called the conduction band. When an electron moves from the valence band to the conduction band, the free state behaves as a positively charged mobile particle and is called a hole, which can also participate in the conduction of current. The gap between these two zones is called the forbidden Eq band. We draw attention to two important differences in the electrical properties of metals and semiconductors.
- The electrical conductivity of a metal is much greater than that of a semiconductor. For example, the conductivity of the semiconductor pure germanium is billions of times smaller than that of most metals. The electrical resistance of a metal increases slowly with increasing temperature. On the contrary, the resistance of a semiconductor can decrease by a factor of thousands or more with even a small change in temperature. In short: a semiconductor is a substance that is very sensitive to temperature changes. A semiconductor is also incomparably more sensitive than metals to light and other external influences. The above-mentioned properties have led to the increasingly widespread use of semiconductors.

Conclusion: Technologies for converting solar energy into electricity are one of the most important areas of scientific and technological progress today. The development of these technologies not only increases the stability of energy supply, but also plays an important role in solving environmental problems. In the future, the efficiency of solar energy is expected to increase further with the help of new materials and innovative technologies.

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METHOD OF CALCULATION OF SOLAR HEAT SUPPLY SYSTEMS AND ASSESSMENT OF THEIR EFFICIENCY

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Abstract. *This article examines a calculation methodology for year-round solar heating systems. Key solar system parameters are determined, including the available solar energy, the heat load for heating and hot water supply, the solar field area, and the volume of the heat accumulator. The energy, thermal engineering, and technical and economic performance of the solar heating system are assessed. Annual fossil fuel savings are determined, and the system's payback period is presented.*

Keywords: *solar heating systems, solar system, solar radiation, solar collectors, heat load, heat accumulator, fuel savings, technical and economic efficiency, payback period.*

Introduction

In today's environment of rising energy consumption and costs, the use of renewable energy sources in heating systems is particularly relevant. One of the most promising areas is the use of solar heating systems, which reduce fossil fuel consumption, minimize harmful emissions, and increase the energy independence of various facilities. Solar heating systems are widely used for heating and hot water supply in residential, public, and industrial buildings. Their efficiency is largely determined by climatic conditions, solar radiation levels, the correct selection of the design and energy parameters of the solar system, and its operating mode. Therefore, it is necessary to perform a sound thermal engineering and technical and economic analysis of solar heating systems.

Thermal calculations for solar installations are complicated by the variability of meteorological factors, such as solar radiation intensity, outdoor temperature, and sunshine duration. Therefore, in practice, aggregated calculation methods are used, which allow the main parameters of the system to be determined with sufficient accuracy, including the area of the solar field, the volume of the heat accumulator, and the expected annual fuel savings. The aim of this study is to develop and apply a calculation method for a year-round solar heating system, as well as to evaluate its energy and technical-economic efficiency. The study determines the optimal parameters of solar collectors, the volume of storage devices, capital and operating costs, and the payback period of the solar system compared to traditional heating systems.

Literary analysis. The issues of using solar energy in heating systems are discussed in detail in a number of scientific and regulatory sources. V. V. Kirillov's methodological guide [1] provides the fundamentals of designing seasonal solar hot water systems, discussing the principles of selecting solar collectors, connection diagrams, and the operating features of solar systems. The author emphasizes the importance of correctly determining the heat load and the parameters of storage devices to ensure stable system operation. The designer's handbook edited by I. G. Staroverov [2] contains general information on the calculation of heating and hot water supply systems for buildings. This source presents methods for determining heat loads, which are used,

among other things, in the design of solar heating systems as additional or autonomous sources of thermal energy.

The regulatory document SNiP II-34-76 "Hot Water Supply" [3] establishes the basic requirements for the design of hot water supply systems, including design temperatures, water flow rates, and sanitary and technical standards. This document is used to justify the parameters of solar hot water systems and their integration with traditional heat sources. The fundamental principles of calculating solar heating systems are presented in the work of W. Beckman, S. Klein, and J. Duffy [4]. The book describes methods for determining incoming solar radiation, the thermal efficiency of solar collectors, and annual thermal energy production. This source is widely used in the thermal engineering calculations of solar systems and the assessment of their energy efficiency.

The collective monograph "Solar Heating and Cooling Systems" edited by E. V. Sarnatsky and S. A. Chistovich [5] examines various solar installation designs, heat accumulation issues, and the specifics of their application in various climatic conditions. The authors note that the efficiency of solar systems significantly depends on the correct selection of design and energy parameters. N. V. Kharchenko's work [6] focuses on individual solar heating and hot water systems. The practical aspects of designing and operating solar systems, as well as their technical and economic indicators, are examined. It is emphasized that the use of solar systems can reduce the consumption of traditional energy resources and improve the energy efficiency of buildings. Thus, an analysis of the literature reviewed demonstrates that solar heating systems are a technically and economically feasible solution. However, their design requires careful thermal engineering calculations taking into account climatic conditions, regulatory requirements, and operating modes, which determines the relevance of this study.

Materials and Methods. Calculating solar heating systems (SHS) [4] involves determining:

- the available solar energy;
- the heating load for heating and hot water supply;
- the energy and geometric characteristics of the solar system;
- the volume of the heat storage device;
- annual fuel savings;
- the technical and economic indicators of the solar system.

The available solar energy [4] is determined based on the total and diffuse solar radiation received by the surface of the solar receiver. Accurately calculating the thermal energy of a solar installation is complicated by the influence of climatic factors. Therefore, aggregated methods are typically used to determine the main SHS parameters – the surface area of the solar field, the volume of the storage devices, and the estimated annual fuel savings. Since the heat supply system operates year-round, and therefore the thermal load in winter will exceed that in summer, the thermal calculation of the solar system must be performed for winter. To ensure maximum heat output, solar collectors are typically installed at an angle to the horizontal, at an optimal tilt angle. The solar collector tilt angle is calculated using the formula [1-4]:

$$\beta = \varphi \pm \delta_a \quad (1)$$

where φ– latitude of the area;

δ_a– average declination of the sun for the period under consideration.

$$\delta = 23{,}45 \cdot sin\left(360 \cdot \frac{284+n}{365}\right) \quad (2)$$

where *n* – ordinal number of the day of the year.

The intensity Q_{ins} of incident solar radiation on an inclined surface oriented in the southern direction can be determined by the formula[1-6]:

$$Q_{ins} = K_1 \cdot S + K_2 \cdot D + K_3 \cdot (S + D) \cdot \rho$$

(3)

where *S* – intensity of direct solar radiation incident on a horizontal surface, MJ/m^2;

D – intensity of diffuse incident solar radiation on a horizontal surface, MJ/m^2;

ρ– albedo of the underlying surface;

K_1, K_2, K_3 – correlation coefficients.

$$K_2 = cos^2 \frac{m}{2} \quad (4)$$

$$K_3 = sin^2 \frac{m}{2} \quad (5)$$

The coefficient K_1 depends on the latitude of the area, the angle of inclination of the SC and the time of year.

Results and discussion.

Knowing the estimated consumer heat load Q^{year} and the amount of incoming solar radiation Q_{ins} (MJ/m^2), we can determine the solar field area $F_{f.a.}$, the required number of solar panels *N* SC, and the storage tank volume V_{TV}:

$$F_{f.a} = \frac{Q^{year}}{Q_{ins} \cdot \eta_{SC}} \quad (6)$$

$$N = \frac{F_{f.a}}{F_{SC}} \quad (7)$$

$$V_{TV} = 0{,}07 F_{f.a}$$

where η_{SC}– average seasonal efficiency of the SC, η=0,5;

N– number of solar collectors, pieces;

F_{SC}– area of one SC, m^2.

Capital costs for a solar heating system are determined by the formula:

$$K_{f.a} = C_{SC} \cdot F_{f.a} + C_{AE} + C_{TV} \cdot V_{TV} \quad (8)$$

where C_{SC} – unit cost of insurance, sum;

C_{AE} – unit cost of auxiliary equipment, pipelines, control valves; instrumentation and automation systems, etc., sum;

C_{TV} – unit cost of TV, sum.

Operating costs for the solar system $Э_{G.S}$ consist of annual expenses for repair and maintenance of equipment [1-4]:

$$Э_{f.a} = Э_{t.r} \quad (9)$$

where $Э_{t.\,r.}$ – annual costs for repair and maintenance of equipment.

The given costs are determined by the formula:

$$П_{f.a} E_n \cdot К_{f.a} + Э_{f.a} \quad (10)$$

The annual savings of organic fuel $B_Э^m$ [5] and material costs $З_{en}^m$ for it during the operation of a solar system are calculated according to the formulas:

$$B_Э^m = \frac{f \cdot Q^Л}{Q_П^{-p} \cdot \eta_П^{-p}} \quad (11)$$

$$З_{en}^m = \left(З_{z.en}^m + З_{u.e}^{mp}\right) \cdot B_Э^m \quad (12)$$

where f – replacement rate. To decide on the cost-effectiveness of the options under consideration, it is necessary to compare capital and operating costs using the payback period determined by the formula:

$$T_{OK} = \frac{K_{f.a} - K_{m.c}}{И_{m.c} - И_{f.a}} \quad (13)$$

where $K_{f.a.}$ – capital investment for the option using a solar system, sum;

$K_{m.c.}$ – capital investment for the option using a traditional heating system, sum;

$И_{m.c.}$ – total annual costs for the option using a traditional heating system, sum;

$И_{f.a.}$ – total annual costs for the option using a solar system, sum [1-5].

Table 1.

Key design parameters of the solar heating system.

Indicator Name	**Designation**	**Meaning**	**Unit of measurement**
Annual Thermal Load	Q_{year}	80–90	GJ/year
Total Solar Radiation on a Horizontal Surface	S + D	≈1500	MJ/m²·year
Solar Radiation on an Inclined Surface	Q_{ins}	1700–1800	MJ/m²·year
Average Seasonal Efficiency of Solar Collectors	η_{SC}	0,5	–
Estimated Solar Field Area	$F_{f.a}$	90–105	m²
Area of a Single Solar Collector	F_{SC}	2,0	m²
Number of Solar Collectors	N	45–52	pieces
Heat Storage Tank Volume	V_{TV}	6,0–7,5	m³
Fuel Replacement Factor	f	0,5–0,6	–
Annual Fossil Fuel Savings	$B_э^m$	2,0–3,0	tons of fuel equivalent/year

Based on the calculated data presented in Table 1, an assessment was made of the key technical parameters of a solar heating system designed to provide a building with year-round thermal energy. The annual heat load of the heating and hot water supply system is assumed to be 80–90 GJ/year, which is typical for residential and public buildings in areas with moderate to high solar activity. The solar heating system calculation was based on approximate climatic and thermal data typical for regions with medium to high solar activity. The system under consideration is designed to heat a building year-round. The average annual total solar radiation incident on a horizontal surface is assumed to be

S + D ≈ 1500 MJ/m².

Taking into account the optimal angle of inclination of the solar collectors and their orientation in the southern direction, the calculated value of solar radiation falling on the inclined surface was

Q_f ≈ 1700–1800 MJ/m² in the year.

The annual heat load of the heating and hot water supply system is assumed to be equal to

Q_{year} ≈ 80–90 GJ.

With an average seasonal efficiency of solar collectors η_{SC}= 0.5, the calculated area of the heliofield was about

$F_{h.p} \approx 90–105$ m².

When using solar collectors with a module area of $F_{SC} \approx 2.0$ m², the estimated number of collectors was N ≈ 45–52. The volume of the heat storage tank, determined using the aggregated dependence, was $V_{TV} \approx 6.0–7.5$ m³. The capital costs of the solar heating system were estimated, taking into account the cost of solar collectors, a storage tank, and auxiliary equipment. Operating costs for the year were assumed to be minimal and include equipment maintenance and repair costs. The annual fossil fuel savings, with a replacement factor of f ≈ 0.5–0.6, amounted to approximately 2.0–3.0 tons of equivalent fuel per year. This demonstrates a significant reduction in the consumption of traditional energy resources and a reduction in operating costs.

Conclusions. This paper examines a comprehensive calculation methodology for a year-round solar heating system based on estimated climate data. Key solar system parameters, including the solar field area and the volume of the heat storage tank, are determined. It is shown that, with an average seasonal solar collector efficiency of approximately 0.5, the use of a solar heating system results in fossil fuel savings of 2.0–3.0 tons of equivalent fuel per year. The estimated payback period for the solar system is 7–10 years. These results confirm the feasibility of using solar heating systems in regions with sufficient solar radiation and can be used in pre-design calculations.

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PHYSICAL FOUNDATIONS OF NANOTECHNOLOGIES AND THEIR PRACTICAL APPLICATIONS

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Abstract*. This article presents a comprehensive analysis of the physical foundations of nanotechnology and the mechanisms of their formation. The structural features of nanomaterials, the principles of their classification, and their role in physical processes are discussed in detail. In addition, the possibilities of applying nanotechnology in various fields of modern science and technology—such as energy, agriculture, medicine, and electronics—are demonstrated through scientific examples. The research results reveal promising prospects for the implementation of nanotechnologies in practical applications.*

Keywords*: nanotechnology, nanomaterials, quantum effects, nanostructures, nanotubes, nanocomposites.*

Introduction

In recent years, nanotechnologies have been developing rapidly and have penetrated deeply into almost all fields of modern science and technology. The term “nano” refers to particles or structures with dimensions on the order of 10^{-9} meters, and materials at this scale exhibit properties that differ significantly from the laws of classical physics. As a result, electrical, optical, thermal, and mechanical processes in nanoscale materials manifest in distinctive ways, setting them apart from conventional materials. The formation and development of nanotechnology are based on the principles of quantum mechanics, solid-state physics, optics, and heat transfer. Because nanoparticles have an extremely large surface area relative to their volume, their chemical reactivity and electrical conductivity increase, while quantum effects exert a significant influence on their optical and physical properties. These factors make nanotechnology a highly relevant field not only for theoretical research but also for practical engineering applications.

In the energy sector, the use of nanomaterials enables increased efficiency of solar panels, reduced energy losses, and the development of high-capacity supercapacitors. In medicine, nanotechnologies create new approaches for targeted drug delivery, early detection of tumor diseases, and tissue regeneration. In agriculture, nano-fertilizers and nanocapsules ensure the gradual delivery of nutrients to plants, increasing crop yields and enabling the controlled application of pesticides. In electronics and information technologies, the use of nanomaterials contributes to device miniaturization, improved energy efficiency, and higher operating speeds. Nanotechnologies also play an important role in addressing environmental challenges by achieving high performance in water, air, and soil purification, as well as in waste recycling processes. Thus, alongside scientific innovation, nanotechnologies make a significant contribution to improving quality of life and promoting sustainable development.

I. Physical Foundations of Nanotechnology

Nanoscale materials differ sharply from macroscopic substances in terms of their structure and properties. These differences are explained by several key factors that manifest in their physical nature.

1. Quantum effects. At the scale of nanoparticles, the energy states of electrons are not continuous but are distributed in discrete levels. As a result, the electrical conductivity, optical response, and magnetic properties of such particles differ significantly from those of macroscopic materials. Due to the quantum size effect, nanoscale devices—particularly sensors and microelectronic systems—operate with high precision and efficiency.

2. Surface effects. As particle size decreases, the total surface area relative to volume increases dramatically. Consequently, the proportion of surface atoms grows, surface energy rises, and the chemical reactivity of the material is enhanced. For this reason, nanoparticles are highly effective when used as catalysts or as active components in biological environments.

3. Size effects. At the nanoscale, properties such as heat capacity, electrical resistance, and density become sensitive to changes in size. Interatomic interaction forces and the nature of phonon propagation also differ from those in bulk materials. As a result, the thermal conductivity, mechanical, and electrical properties of nanoscale materials change, enabling their application in advanced technological processes.

These distinctive factors allow nanotechnologies to be applied with high efficiency in sectors such as energy, medicine, electronics, and agriculture. The physical properties of matter are directly dependent on particle size. As size decreases, the surface area of particles increases and the relative proportion of surface atoms rises. Consequently, physical processes occurring in nanoscale materials differ markedly from those in macroscopic materials. While under ordinary conditions material properties are largely governed by the laws of classical mechanics and thermodynamics, at the nanoscale they are shaped by quantum mechanics and surface energy effects.

For example, a macroscopic metal exhibits smooth electrical conductivity, whereas at the nanoscale, due to the quantization of electron energy levels, its conductivity changes. Therefore, as the dimensions of a material decrease, its physical behavior changes proportionally. The main differences between nanoscale and macroscale materials are presented in Table 1, which highlights the distinctions in their electrical, thermal, and mechanical properties.

Table 1.

Comparison of Material Properties at the Nano and Macro Scales

Property type	Macro scale	Nano scale
Electrical properties	Electrical conductivity is continuous and governed by classical laws	Electron energy levels are quantized; conductivity becomes discrete
Optical properties	Color and absorption spectra mainly depend on the type of material; particle size is not critical	As size decreases, color and absorption spectra change; for example, gold nanoparticles appear red or purple
Mechanical properties	Material strength is limited and sensitive to deformation	Due to increased density of interatomic bonds, mechanical strength increases by 10–100 times
Thermal properties	Phonons move freely; thermal conductivity is high	Phonon scattering increases, resulting in reduced thermal conductivity

Chemical reactivity	Low reactivity due to small surface area	High reactivity due to large surface area
Physical models	Governed by the laws of classical mechanics and thermodynamics	Quantum mechanics, surface energy, and size effects play a dominant role
Electrical properties	Electrical conductivity is continuous and follows classical laws	Electron energy levels are quantized; conductivity exhibits discrete behavior

II. Main Types of Nanomaterials

1. Graphene

Graphene is a two-dimensional lattice composed of a single layer of carbon atoms. It is distinguished by its exceptionally high electrical conductivity— in some cases even higher than that of copper. Mechanically, graphene is approximately 200 times stronger than steel. Therefore, it is widely used in the development of nanoelectronics, batteries, and composite materials.

2. Carbon nanotubes

These materials are cylindrical nanostructures composed of carbon atoms and are among the strongest materials known. Owing to their unique electrical and mechanical properties, carbon nanotubes can efficiently absorb electromagnetic waves and transmit electrical energy at very high speeds. As a result, they are used in antennas, sensors, and energy systems.

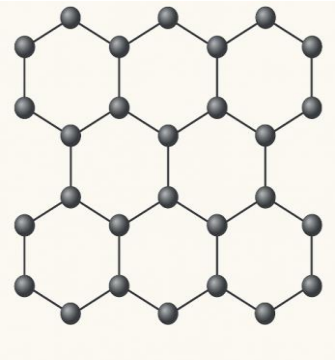
3. Nanocomposites

Nanocomposites are materials obtained by incorporating nanoparticles into polymer, metal, or ceramic matrices. The main advantage of nanocomposites is that their mechanical strength, thermal resistance, and wear resistance are significantly higher than those of conventional materials. They are widely used in aviation, automotive manufacturing, and construction.

4. Quantum dots

Quantum dots are semiconductor nanoparticles that exhibit size-dependent optical and electronic properties. Their light emission or absorption range varies according to particle size. Owing to these characteristics, quantum dots are widely used in display technologies, lasers, medical imaging, and biomarker systems.

Atomic-scale structure of the graphene lattice. Figure 1.



Practical Applications of Nanomaterials

Nanotechnology is currently regarded as one of the most promising fields of modern science and technology. Its practical applications are widely demonstrated across almost all sectors, including energy, medicine, agriculture, electronics, mechanical engineering, and environmental protection.

Nanotechnologies are currently penetrating almost all areas of human activity. Owing to their unique nanometer-scale structure, high surface activity, quantum effects, and distinctive physical properties, new technological solutions and innovative opportunities are emerging across various fields.

In the energy sector, the use of nanomaterials serves to increase the efficiency of energy production processes and reduce losses. For example, electrodes based on graphene or carbon

nanotubes have increased the efficiency of solar cells by up to 25–30%. At the same time, nanocomposite-based supercapacitors and advanced energy storage systems are being developed.

In medicine, nanotechnologies have initiated a new stage in medical diagnostics and treatment methods. The use of nanoparticles enables early detection of tumor diseases, targeted delivery of pharmaceuticals, and stimulation of cell regeneration through nanorobots. Such approaches not only improve treatment effectiveness but also reduce adverse effects on the human body.

In agriculture, nanomaterials play an important role in increasing crop yields, protecting plants from pests, and maintaining soil fertility. Through the use of nano-fertilizers and nanocapsules, nutrients are delivered to plants in a controlled manner, which helps reduce pesticide use and preserve ecological balance.

In electronics and mechanical engineering, nanomaterials enable the miniaturization of modern devices and improve energy efficiency. Processors, displays, and memory systems developed on the basis of carbon nanotubes and quantum dots operate at high speeds while consuming less energy.

In the field of environmental protection, technologies based on photocatalytic nanomaterials are being developed to purify water, air, and soil. Such materials decompose harmful substances and improve waste recycling processes, thereby ensuring environmental sustainability.

Thus, the development of nanotechnology creates broad opportunities for increasing efficiency, rational use of resources, and environmental protection in strategic sectors such as energy, medicine, agriculture, electronics, mechanical engineering, and ecology. The application areas of nanomaterials, their main types, and scientific outcomes are summarized in Table 2.

Table 2.

Practical Applications of Nanomaterials

Application field	Types of nanomaterials used	Main purpose or outcome	Practical examples
Energy	Graphene, carbon nanotubes, nanocomposites	Increasing the efficiency of solar cells, creating supercapacitors, developing efficient energy storage and transmission systems	Solar cells, supercapacitors, hydrogen storage systems
Medicine	Gold and silver nanoparticles, quantum dots, nanocapsules	Targeted drug delivery, early detection of cancer cells, accelerating tissue repair and regeneration using nanorobots	Cancer-targeting nanodrugs, biosensors
Agriculture	Nano-fertilizers, nanopesticides, silicon and titanium dioxide nanostructures	Stimulating plant growth, providing sustainable pest protection, improving soil fertility and reducing environmental pollution	Nanocapsulated fertilizers, water-purifying nanofilters

Electronics and information technologies	Quantum dots, carbon nanotubes, graphene	Developing nanoprocessors, high-resolution displays, and energy-efficient memory systems; device miniaturization	Quantum-dot displays, nanoprocessors
Environmental protection	Photocatalytic TiO_2, ZnO, and Fe_3O_4 nanomaterials	Neutralizing industrial waste, purifying water and air, developing technologies to decompose heavy metals and organic pollutants	Nanofiltration membranes, catalysts for decomposing harmful gases
Mechanical engineering and construction	Nanocomposites, ceramic nanostructures	Creating wear-resistant coatings, lightweight and durable structural materials, increasing mechanical strength	Nanocomposite coatings, lightweight yet strong structures

Nanotechnologies enable the targeted delivery of pharmaceuticals. For example, nanocapsules penetrate only damaged cells and do not affect healthy ones.

3.1. Energy

In the energy sector, nanomaterials are creating new technological opportunities. Their use makes it possible to produce highly efficient solar cells, heat-exchange systems, and supercapacitors. For instance, graphene-based electrodes significantly enhance energy storage capacity; research results indicate that their energy capacity can increase by up to threefold.

3.2. Medicine

In medicine, nanorobots are being used to detect oncological diseases, deliver drugs precisely to target cells, and support tissue repair and regeneration.

3.3. Agriculture

In agriculture, nanotechnologies play an important role not only in increasing crop yields but also in conserving resources, ensuring environmental safety, and protecting plants from diseases. Their application is expected to contribute to the development of sustainable and efficient agriculture on a global scale.

3.4. Electronics and Information Technologies

In electronics and information technologies, quantum computers, nanochips, and nanosensors operate at very high speeds. For example, IBM has developed a 2 nm transistor chip, enabling the integration of up to 50 billion transistors within one square centimeter.

3.5. Environmental Protection and Nanotechnology

In recent years, humanity has faced serious environmental challenges, including pollution of air, water, and soil, the increase in industrial waste, and the rise in greenhouse gas emissions—all of which negatively affect the global climate and human health. From this perspective, nanotechnologies are recognized as effective and innovative solutions for environmental protection. Owing to their catalytic, adsorptive, and photochemical properties, nanomaterials actively participate in various ecological processes.

3.6. Application of Nanomaterials in Mechanical Engineering

Nanotechnology enables improvements in product quality, extended service life, and reduced energy consumption in the fields of mechanical engineering and construction. Owing to the unique physical and chemical properties of nanomaterials, they serve as a basis for creating lightweight yet highly durable structures. In particular, nanocomposite polymers and nanoalloys are widely used in automotive manufacturing, aviation, and the production of construction materials.

4. Future Prospects and Challenges

Alongside the rapid advancement of nanotechnology, a number of ecological, ethical, and social challenges are also emerging. One of the key unresolved issues is the insufficient understanding of the effects of nanoparticles on living organisms and ecosystems. Due to their extremely small size and high surface reactivity, nanoparticles can penetrate biological membranes, accumulate in tissues, and potentially cause toxic effects. However, the long-term impact of such interactions has not yet been fully investigated. Despite these challenges, the future prospects of nanotechnology are highly promising. The development of smart materials capable of adapting to external stimuli, nanorobots for precise medical interventions, and artificial photosynthesis systems for sustainable energy production may significantly transform modern society. These innovations have the potential to address global challenges such as energy shortages, environmental degradation, and healthcare accessibility, thereby improving overall quality of life.

In conclusion, nanotechnologies are grounded in the most advanced achievements of modern physics and create vast opportunities for humanity by enabling the study and control of material properties at the nanoscale. Their application in medicine, energy, agriculture, and electronics is expected to significantly increase economic efficiency, enhance technological performance, and support sustainable development in the future. A deep understanding of physical principles and the ability to manage processes at the nanoscale are becoming central directions of twenty-first-century science. As research and innovation in this field continue to expand, nanotechnology is poised to play a decisive role in shaping future scientific progress and improving quality of life.

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SCIENTIFIC AND TECHNOLOGICAL STUDY OF THE PROCESS OF OBTAINING HIGH-PURITY P-1 GRADE PARAFFIN FROM TECHNICAL PARAFFIN

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Abstract. *In this paper, the process of obtaining high-purity P-1 grade paraffin from technical paraffin was investigated using a comprehensive scientific and technological approach. The process includes the stages of solvent deoiling, crystallization, sweating, adsorption purification, and vacuum drying. At each stage, changes in the main quality indicators of paraffin were analyzed, and the corresponding physicochemical mechanisms were substantiated. According to the research results, the product obtained using the proposed technological scheme fully complies with the requirements of GOST 23683–89.*

Keywords: *technical paraffin, P-1 paraffin, solvent deoiling, crystallization, sweating, adsorption.*

Introduction

It is widely acknowledged that paraffins are a strategically important product of the oil refining industry, the production and quality of which directly impact the efficiency of many industries. Paraffins are widely used as insulating materials in the electrical industry, as auxiliary substances and packaging materials in the pharmaceutical industry, as protective coatings and process lubricants in the food industry, and as a material with moisture- and gas-impermeable properties in the packaging industry [1–3]. One of the most sought-after products in these industries is grade P-1 paraffin, which is characterized by a high degree of purity, very low oil content (typically less than 0.3%), a colorless or light appearance, and a stable and narrow melting point range [4,5]. These quality indicators are the main factors determining the practical properties of paraffin, which are evaluated based on strict regulatory requirements, particularly in the electrical and pharmaceutical industries.

Technical paraffin is obtained primarily through vacuum distillation of oil and dewaxing of oil fractions. However, this product contains significant amounts of petroleum fractions, aromatic hydrocarbons, resinous-asphaltene substances, as well as coloring and oxidation-prone components [6,7]. These components result in a darker color of technical paraffin, uneven melting point, and reduced dielectric properties. It has been extensively argued that producing high-quality P-1 grade paraffin through deep purification of technical paraffin is one of the pressing scientific and practical challenges of the modern oil refining industry. In practice, methods such as solvent degreasing, selective crystallization, thermal impregnation, adsorption purification, and vacuum drying are used for paraffin purification [8–10]. Each of these methods is aimed at separating a specific group of impurities from the paraffin, and their optimal use significantly improves product quality.

Recent scientific research has shown that optimizing process parameters (temperature, solvent ratio, crystallization rate, and adsorbent type) in paraffin deep purification processes is

crucial for obtaining a highly pure product [11–13]. In particular, strict adherence to the requirements of GOST 23683–89 in the production of grade P-1 paraffin ensures the product's competitiveness. It should be noted that the aim of this study was to study the process of producing pure grade P-1 paraffin from technical paraffin using an integrated scientific and technological approach, analyze changes in quality indicators at each stage, and substantiate an optimal process flowsheet.

Materials and methods

Description of raw materials. Technical paraffin that complies with the requirements of GOST 23683–89 was used in the study.

Table 1 - Key Quality Indicators of Technical Paraffin

Indicator	**Value**
Melting temperature, °C	49–52
Oil quantity, %	1,5–2,2
Color	Blond
Mechanical impurities	Existent

Analysis methods

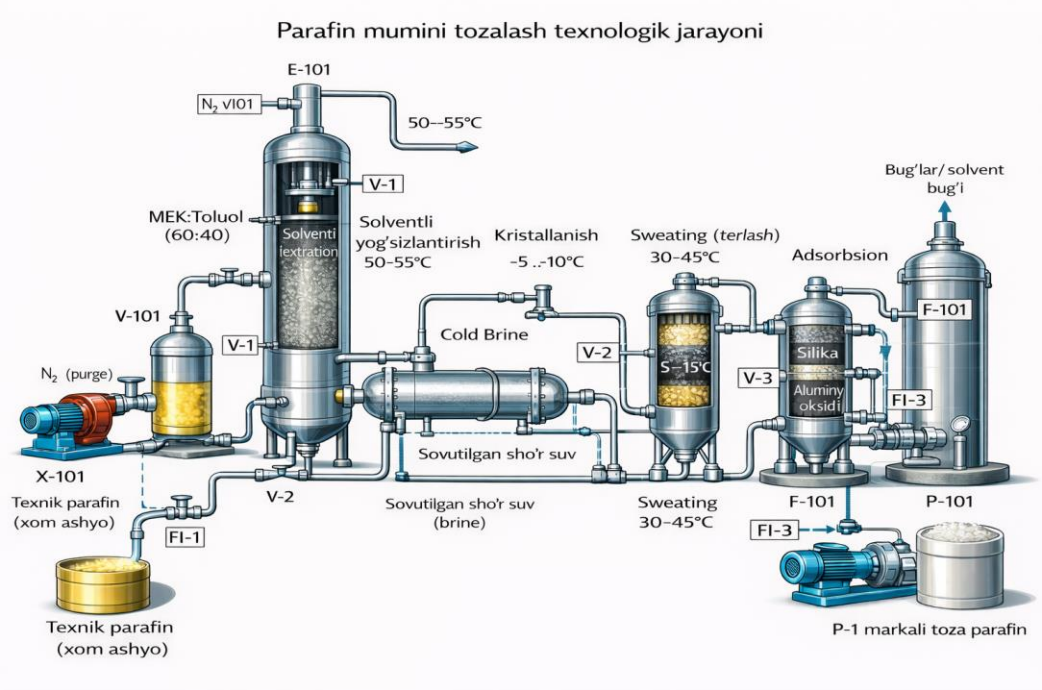
Quality indicators were determined based on the following standards:

fat content – GOST 10227–86;

melting point – GOST 7142–74;

color – GOST 20284–74;

moisture content – GOST 2477–65 [5–8].



Brief process description. Technical paraffin is first dissolved in a MEK-toluene solution during the solvent degreasing step and separated from the oil and aromatic components. The resulting solution is cooled to -5 to -10°C, where n-paraffins crystallize. The resulting crystals are heated at 30–45°C during a "stripping" process and purified to remove residual oils. The paraffin is then passed through an adsorption column based on silica gel and Al_2O_3 to remove color and

trace impurities. Finally, the solvent and moisture are removed under vacuum in a filter dryer, yielding pure P-1 grade paraffin that meets GOST requirements.

Results and Discussion

Solvent Degreasing Step

It is well known that technical paraffin was dissolved in a MEK: toluene mixture (60:40) at 50–55°C. At this stage, oil fractions and aromatic hydrocarbons were selectively transferred into the solvent. Research has shown that the process of producing pure grade P-1 paraffin from technical paraffin must be based on multi-stage deep purification. Each process stage has a different but interrelated impact on the quality of the paraffin. The polarity and solubility of oil components in solvents are higher than in n-paraffins [6].

Table 2 - Quality changes during the degreasing stage

Indicator	Before	after
Oil quantity, %	1,9	0,9
Color	yellow	yellow-eyed

Crystallization Stage

The solution was cooled to -5…-10°C. This resulted in crystallization and separation of high-molecular-weight n-paraffins. Solvent degreasing is the primary initial stage determining paraffin quality. The high solubility of oil fractions in the MEK-toluene system ensures their selective separation from the paraffin matrix. Results showed that this stage resulted in a nearly twofold reduction in oil content (1.9% → 0.9%). This significantly increased the efficiency of the crystallization stage, as oils are one of the main factors preventing the formation of a crystal lattice. Literature data also confirm that paraffin develops an uneven structure during crystallization if the degreasing stage is insufficiently effective [1, 6].

n-paraffins have a high melting point and form a crystal lattice at low temperatures [7].

Table 3 - Parameters after crystallization

Indicator	Value
Oil quantity, %	0,65
Melting temperature, °C	53,2

Sweating stage. The crystals were slowly heated at 30–45 °C. At this stage, residual oils were removed by capillary diffusion. The choice of a temperature range of −5…−10 °C during the crystallization stage is scientifically justified. At this temperature, high-molecular n-paraffins separate into crystalline state, while low-molecular hydrocarbons and oil components remain in the liquid phase. The results of the study showed that after crystallization, the melting temperature of paraffin increased above 53 °C. This is explained by the densification of the crystal lattice and improvement of molecular ordering. At the same time, the reduction of the oil content to 0.65% created favorable conditions for the sweating stage. Low-molecular components inside the crystal lattice migrate to the external phase under the influence of heat [8].

Table 4 - Quality changes during sweating

Temperature, °C	Oil quantity, %
30	0,55
40	0,45

Steam impregnation is a critical step in the deep purification of paraffin wax, removing residual oils remaining in the crystal lattice. With slow heating in the temperature range of 30–45°C, oil components migrate to the outer phase via capillary diffusion. According to the results obtained, the oil content after steam impregnation decreased to 0.45%. This value is close to the limit established for P-1 paraffin, indicating optimal steam impregnation. Literature suggests that steam impregnation can be performed too quickly or at high temperatures, which can lead to partial melting of the paraffin and product loss [3, 7].

Adsorption Purification

It is commonly assumed that paraffin was passed through layers of silica gel and active Al_2O_3. Adsorption purification is the final step in determining the quality of the paraffin wax. Adsorbents based on silica gel and active Al2O3 selectively retain aromatic hydrocarbons, coloring oxygen and sulfur compounds.

The study results showed that after adsorption treatment, the paraffin became optically colorless, and the oil content decreased to 0.32%. This is explained by the large surface area of the adsorbents and the presence of Lewis sites. It was found that paraffin obtained without this step does not meet the requirements of electrical engineering and pharmaceuticals. The Lewis sites of the adsorbents selectively retain aromatic and coloring compounds [14].

Table 5 - Parameters after adsorption treatment

Indicator	**Value**
Color	colorless
Oil quantity, %	0,32

Vacuum drying. The solvent and moisture were removed under vacuum at 90–110 °C and 0.06–0.08 MPa.

Final product

Table 6 – Final quality parameters of paraffin wax of grade P-1

Indicator	**Obtained**	**GOST requirement**
Melting temperature, °C	55,6	≥55
Oil quantity, %	0,32	≤0,5
Color	Colorless	colorless

Interdependence of Quality Indicators Between Stages

The results of the discussion show that the process stages are closely interrelated:

- Solvent degreasing determines crystallization efficiency;
- Crystallization affects the depth of the evaporation process;
- Evaporation reduces the load on adsorption purification.

Therefore, reducing or skipping any stage of the process leads to a decrease in the quality of the final product. Only an integrated approach ensures the production of grade P-1 paraffin [15].

The graph shows the gradual reduction in oil content during the main stages of the process of producing grade P-1 paraffin from technical paraffin. The oil content in the initial technical paraffin averages 1.9%. After the solvent degreasing stage, this value decreases to 0.9%, due to the selective solubility of oil fractions in the solvent. During the crystallization and pressing stages, the oil content decreases to 0.65% and 0.45%, respectively. After final adsorption purification, the oil content reaches 0.32%, which is below the GOST requirements for grade P-1 paraffin.

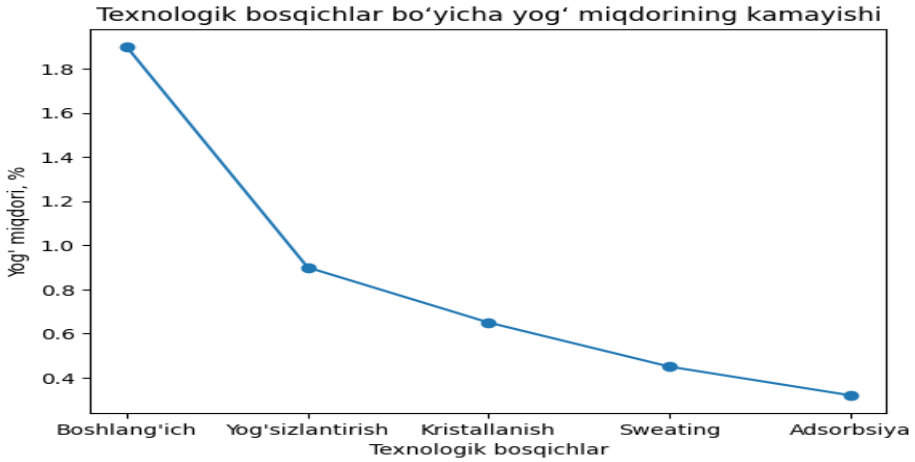


Figure 1. Reduction in oil content by process stages

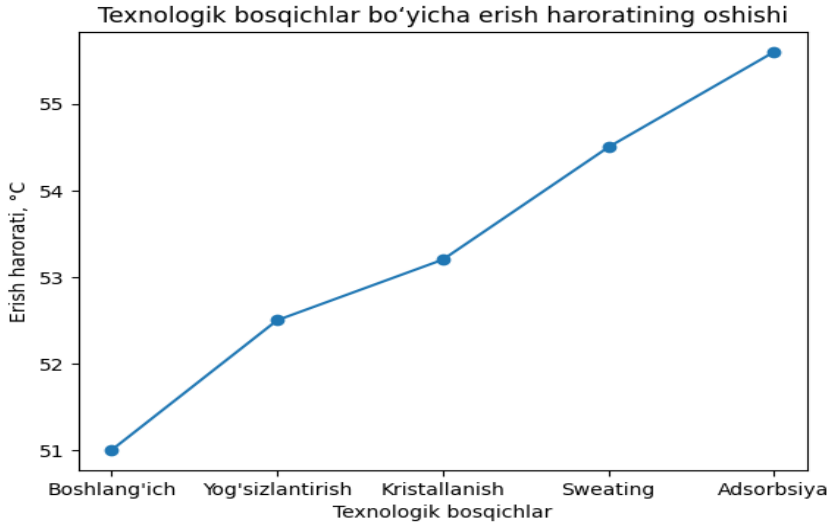


Figure 2. Melting Point Increase by Process Stages

This graph shows the change in paraffin melting point during the process.While the melting point of the original technical paraffin is approximately 51°C, after solvent degreasing, this value increases to 52.5°C. Crystallization and separation processes increase the ordering of the paraffin molecules, and the melting point rises to the range of 54–55°C. After adsorption purification, the melting point reaches 55.6°C, which is higher than the standard value for grade P-1 paraffin.

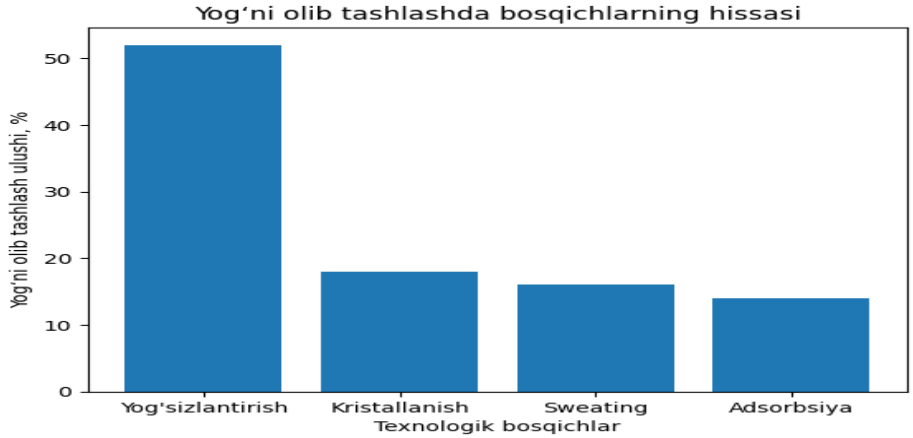


Figure 3. Contribution of Process Steps to Oil Removal

This histogram shows the relative contribution of each process step to the removal of oil components from technical wax. As can be seen from the diagram, the solvent degreasing step

accounts for the majority of the oil removal (≈52%). This is explained by the high solubility of oil fractions in the MEK-toluene system. The contributions of the crystallization and impregnation steps are 18% and 16%, respectively; these processes serve to remove residual oils remaining in the crystal lattice. Although the contribution of adsorption purification is relatively small (≈14%), it plays a significant role in ensuring compliance with final quality requirements.

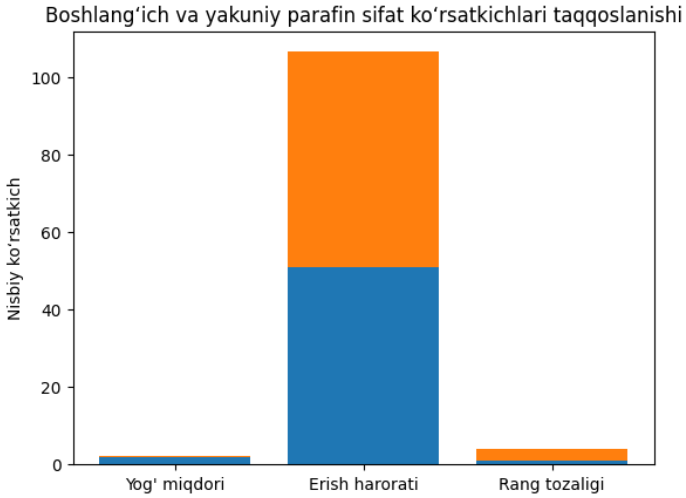


Figure 4. Comparison of quality indicators of the initial and final paraffin.

The diagram compares the key quality indicators (fat content, melting point, and color purity) of technical paraffin and final P-1 paraffin. It is observed that the fat content in the final product has decreased several times compared to the initial technical paraffin, while the melting point has increased significantly. The improvement in color purity clearly demonstrates the effectiveness of the adsorption purification stage. These results confirm full compliance with regulatory requirements for P-1 paraffin.

CONCLUSIONS

The conducted studies have shown that the process of producing high-purity P-1 paraffin from technical paraffin requires a multi-stage and comprehensive technological approach to purification. During the study, the influence of solvent degreasing, crystallization, pressing, adsorption purification, and vacuum drying on the paraffin quality indicators was systematically studied and scientifically substantiated. It was found that the solvent degreasing step is a key stage of the process, and it is at this stage that the selective separation of the majority of the oil fractions occurs. A sharp reduction in oil content at this stage increases the efficiency of the subsequent crystallization process, ensuring uniform and dense formation of the paraffin crystal lattice

When the crystallization stage was carried out in the temperature range of -5 to -10°C, effective separation of high-molecular-weight n-paraffins was observed. This stage played a significant role in increasing the melting point of the paraffin and improving its thermal stability. The "sweating" process, carried out after crystallization, enabled deeper purification of the paraffin by removing residual oils remaining in the crystal lattice through capillary diffusion. The fact that the oil content at this stage approached the standard limit indicates optimal process performance.

The adsorption purification stage was assessed as a decisive factor determining the final quality of the paraffin. The use of silica gel and active Al2O3-based adsorbents enabled the effective retention of coloring, aromatic, and heteroatomic compounds. As a result, the paraffin became optically colorless and began to meet high quality requirements. Vacuum drying in a final filter-dryer completely removed residual solvent and moisture, ensuring stable product storage. A

step-by-step analysis revealed that each stage of the process is closely interconnected, and reducing or bypassing any one of them leads to a significant reduction in the quality of the final product. Only a process implemented using an integrated approach can fully comply with the requirements of GOST 23683–89 for P-1 grade paraffin.

It is well known that obtained results have not only scientific but also practical significance. The proposed process flowsheet can be adapted to existing dewaxing units at oil refineries, enabling the advanced processing of technical paraffins to produce a high-added-value product. This will help improve production efficiency, reduce waste, and increase economic profit.

Energy optimization, adsorbent regeneration, and the transition to continuous industrial operation are considered promising areas for future research. Furthermore, the potential for using new selective solvents and highly efficient adsorption materials to further improve paraffin quality is of scientific significance.

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PREPARATION OF ANION EXCHANGERS SELECTIVE FOR COPPER AND MOLYBDENUM IONS

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Abstract. *A novel method for obtaining an anion exchanger through the polycondensation of furfural with melamine and formaldehyde (DFA) has been developed. The properties and structure of the synthesized anion exchanger were studied using a combination of elemental analysis, physicochemical methods, as well as alkalometric and potentiometric titration, mass spectrometry, IR spectroscopy, thermogravimetry, and photocolorimetry. The main physicochemical and chemical characteristics of the anion exchangers – such as sorption of copper, nickel, molybdenum, and other ions, the degree of dissociation of ionogenic functional groups, and others – were investigated. Correlations between the chemical composition of the initial monomers, their sorption and physicochemical properties, and the characteristics of the resulting anion exchangers were established, demonstrating the potential for producing ion exchangers that can serve as import substitutes.*

Keywords: *furfural, melamine, diphenylamine, anion exchanger, sorption, polycondensation, ion exchange polymer, wastewater treatment, sustainable development.*

Introduction

Nowadays, the rapid development of industry, the resolution of environmental problems, and the production of competitive and environmentally friendly products increasingly require the implementation of modern technologies. In recent years, the introduction of innovative approaches and new developments has significantly increased the production volume and quality of industrially essential products. In this context, the use of chemically active substances for the efficient purification of wastewater through the synthesis of cation exchangers and anion exchangers, as well as the improvement of their physicochemical and sorption properties, is of particular scientific and practical importance. These technologies not only contribute to environmental protection but also enhance resource efficiency, product quality, and safety in industrial processes. Thus, the development of cation and anion exchangers and the enhancement of their properties represent a crucial stage in the advancement of modern industrial and ecological technologies.

Worldwide, the development of ion-exchange polymers, including anion exchangers, for the selective recovery of rare and valuable metal ions from industrial wastewater is of significant scientific and practical importance. This involves expanding the raw material base for their production and scientifically substantiating the corresponding solutions. In particular, it is necessary to determine the chemical composition, physicochemical properties, and sorption characteristics of the initial raw materials suitable for the synthesis of ion-exchange polymers; to obtain a weakly basic anion exchanger with complex-forming and selective sorption properties through the polycondensation of furfural with melamine and formaldehyde (DFA); and to identify the optimal conditions for anion exchanger synthesis, including the effects of reaction temperature,

the ratio of initial components, and the concentration of catalysts on the properties of the resulting anion exchanger [1–4].

In the Republic of Uzbekistan, theoretical and practical results are being achieved in the development and implementation of technologies for producing cation and anion exchangers based on local raw materials for the purification of industrial wastewater. The third direction of the "Action Strategy for the Further Development of the Republic of Uzbekistan" emphasizes the critical task of developing high-tech industrial processing sectors, primarily through the deep processing of local raw material resources, to produce high-quality finished products. In this context, conducting scientific research on the production of new ion-exchange anion resins from local industrial waste is of particular importance.

The aim of the study is to obtain complex-forming anion exchangers through the polycondensation of furfural with melamine and diphenylamine, and to apply them for the removal of metal ions from wastewater in the chemical and hydrometallurgical industries.

To achieve this aim, the following tasks were carried out:

– determination of the chemical composition, physicochemical properties, and sorption characteristics of the initial raw materials suitable for the synthesis of ion-exchange polymers;

– synthesis of a weakly basic anion exchanger with complex-forming and selective sorption properties toward colored and rare metal ions (copper, molybdenum, etc.) through the polycondensation of furfural with melamine and formaldehyde (DFA);

– identification of the optimal conditions for anion exchanger synthesis and investigation of the effects of reaction temperature, the ratio of initial components, catalyst concentration, and other parameters on the properties of the resulting ion-exchange anion;

– development of the anion exchanger production technology and characterization of the obtained ion-exchanger in terms of physicochemical and sorption properties, including the sorption of copper, nickel, molybdenum, and other ions, sorption capacity, and the degree of dissociation of functional groups.

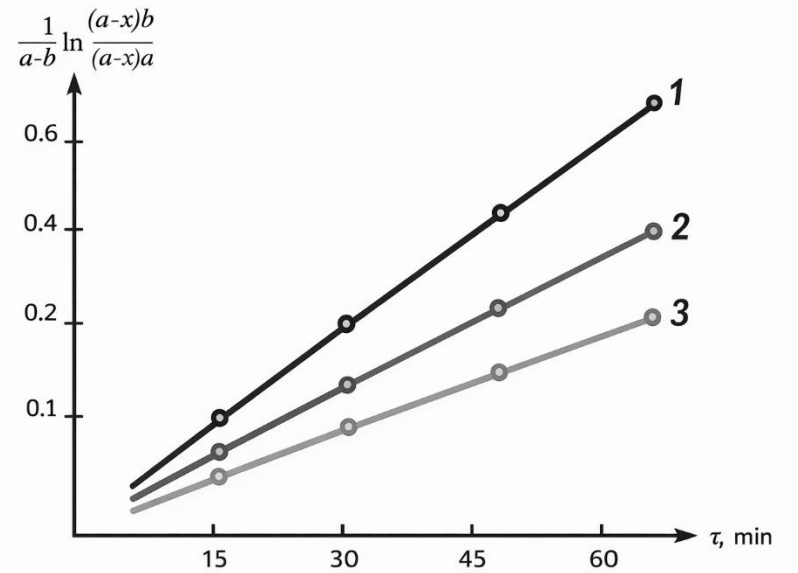


Figure 1. Change in the logarithm of the concentrations of the reactants during the reaction at different temperatures: 1 – 130°C; 2 – 120°C; 3 – 110°C.

In order to obtain an anion exchanger with high thermo-chemical stability, mechanical strength, and selective properties toward molybdenum ions, furfural was used instead of formaldehyde as the crosslinking agent in the synthesis. The formation patterns of the anion-

exchange polymer through the polycondensation of furfural with melamine (DFA) were investigated. The presence of aromatic units (DFA) together with the heterocycles of furfural in the anion exchanger structure significantly enhances its chemical, thermal, and mechanical stability [5].

To ensure uniform polycondensation, the reaction was carried out in solvents such as ethanol, isoamyl alcohol, and dimethylformamide (DMF), among others. The highest polymer yield was observed when ethanol and DMF were used. When one part by weight of solvent and one part by weight of melamine were applied, the polycondensation proceeded uniformly, resulting in an anion exchanger with sufficient exchange capacity and good mechanical strength. The kinetics of the polycondensation reaction between melamine and furfural was studied at 100°C, 110°C, 120°C, and 130°C, with a constant molar ratio of melamine to furfural of 1.5:1.0. The experimental results are presented in Figure 1.

In calculating the reaction rate constant from the change in furfural concentration, it is suggested that polymer formation occurs through the interaction between the carbonyl group of furfural and the reactive hydrogen atoms of the melamine amino groups. In the first stage of the reaction, the formation of methylol derivatives is taken into account [6].

$$R - NH_2 + R_1 - C\begin{matrix}O\\H\end{matrix} \longrightarrow R - NH - R_1 - CH_2OH$$

In the substitution of both hydrogen atoms of the amine, dimethylol derivatives can be formed.

$$R - NH_2 + 2\,R_1 - C\begin{matrix}O\\H\end{matrix} \longrightarrow R - N(R_1 - CH_2OH)_2$$

The methylol derivatives formed in this way begin to interact with each other by releasing water and forming cross-links that connect individual amine molecules. The experimental results are consistent with the IR spectroscopic studies of the initial substances. It was found that the degree of change in polymers at different temperatures depends on the duration of the process. Based on these results, the logarithmic dependence of the concentration of the reacting substances on time at various temperatures was determined. For the calculations, results corresponding to a degree of change not exceeding 30% were used. As can be seen from Figure 1, the linear relationship along the $\frac{1}{a-b}\ln\frac{(a-x)b}{(b-x)a} - \tau$ axis indicates that this process corresponds to reactions described by a second-order equation [7–8]. The temperature dependence of the rate constants follows the Arrhenius equation. The activation energy of the melamine–furfural polycondensation reaction, determined from the lg k versus 1/T plot, was found to be 98 kcal/mol. The effect of the initial substance ratios on the polycondensation process was studied. The dependence of the reaction rate constant on the furfural concentration showed that at 120 °C, the increase of the rate constant with the furfural concentration in the reaction medium is linear. Thus, based on the results of the conducted study, the optimal conditions for the reaction were determined as follows: T = 120 °C, DMF as the medium, and a furfural-to-melamine molar ratio of 2.0:1.0. The properties of the obtained anionite are presented in Table 1. The individual patterns of ion exchange in the synthesized anionite have been studied, and they can serve as a basis for the physicochemical characterization of the synthesized anionite. Physicochemical investigation of anionites allows identifying ways to modify certain properties of the ionites. The properties of the obtained anionite

were compared with those of industrial anionites AN-31, AN-2F, and FAN anionite, which is based on furfural and polyethylene polyamine. Additionally, industrial anionite AN-1, which contains a triazine ring in its structure, was used [9].

Table 1

Main physicochemical properties of anionites

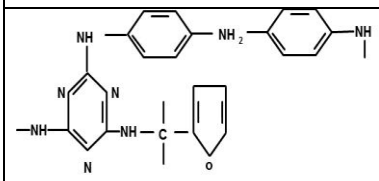
Indicators	Unit of measure-ment	Anionite based on melamine, furfural, and diphenylamine	FBG anionite based on benzoguanidine and furfural	FDG anionite based on diphenylamine and furfural	AN-1 anionite based on melamine and formaldehyde
Moisture	%	-	-	-	15
Static exchange capacity (SEC) for 0.1 N solutions of: Sodium chloride Hydrochloric acid Nitric acid Sulfuric acid	g/ml	 0,6 4,5-5,0 5,08 5,95	 - 4,8-5,0 4,6 4,5	 - 6,5-7,2 6,2 6,3	 0 3,96 4,17 4,95
Capacity of the swollen anionite in OH^- form	ml/l	1,6-1,8	2.8	3.8	2,5
Chemical stability. Static exchange capacity (SEC) in 0.1 N HCl solution after boiling the anionite for 30 minutes in: 5 N NaOH 5 N H_2SO_4	mg-eq/l	 4,5 4,2	 4,5 4,6	 6,3 6,4	 - -
Thermal stability. Static exchange capacity (SEC) in 0.1 N HCl solution after boiling the anionite in water for 20 minutes	mg-eq/l	4,8-5,0	4,7	6,4	-
Sorption of molybdenum ions and ammonium	mg/g	206	354	200	165

molybdate mixture with 1 N Na_2SO_4 solution ($C_{initial}$ = 1 g/l, pH = 4.5–5)					

One of the main indicators that determines the physicochemical properties of ions is the exchange capacity, which is usually determined using 0.1 N solutions of mineral acids found in industrial solutions. Table 2 presents the exchange capacities of anionites obtained by various methods.

Table 2

Exchange capacity of the obtained anionite

Anionite	**Functional groups of the anionite**	**Exchange capacity, mg-eq/g**			**pK$_{OH}$**
		Theoretical	**Static**	**Calculated based on N%**	
	-NH_2 -NH_3 -N=	5.3	5.5	5.3	8.3

As can be seen from Table 2, the total capacity of the anionite determined by various methods is almost the same.

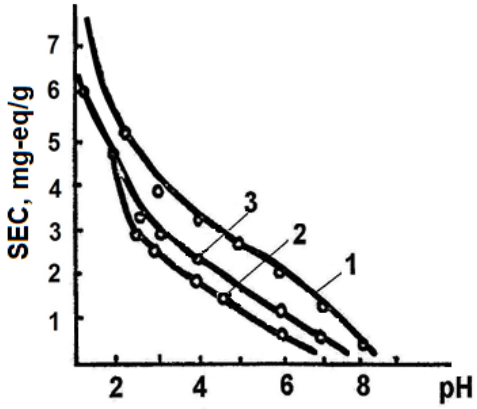


Figure 2. Dependence of anionites' exchange properties on the pH environment:
1 – AN-31; 2 – FAN; 3 – synthesized anionite

In this study, the ion-exchange capacity of the obtained anionite was also investigated in relation to the medium pH and the involvement of ionogenic groups using the potentiometric titration method (Figure 2). Analysis of the curves in Figure 2 shows that during all tests, the titration curves of the anionites decrease uniformly, indicating that they belong to the group of weakly basic anionites.

The presence of functional groups in the obtained anionites and the initial substances was confirmed by IR spectra. In the spectrum of the obtained anionite, absorption bands in the 650–900 cm^{-1} region are observed, which are associated with the vibrations of =NH and $–NH_2$ groups, although the intensity of these bands is somewhat reduced. The absorption band at 840 cm^{-1} in the spectrum corresponds to para-substitution in the diphenylamine (DFA) ring. The absence of absorption bands in the 1670–1695 cm^{-1} region, which corresponds to the carbonyl group of furfural, indicates that furfural interacts with melamine and DFA through the aldehyde group [10].

The sorption of cations by the obtained anionites from solutions of copper, nickel, cobalt, zinc, sulfate, and cadmium chloride was studied under static conditions. To obtain information about the state of the ionogenic groups of the anionite and its anion exchange capacity, the effect of complex formation on the exchange capacity was utilized. As a model, the sorption of copper ions by the obtained anionite was used. Potentiometric titration curves were obtained both in the absence and in the presence of copper ions.

Figure 3 shows the potentiometric titration curves of the OH-form anionite without copper ions (first curve) and in the presence of copper ions (second curve). Comparison of these curves shows that complex formation does not affect the total exchange capacity of the anionite (the position of the inflection points in the titration curves remains unchanged). This can be explained by considering the reaction mechanism when copper ions that form complexes are either present or absent in the anionite [10].

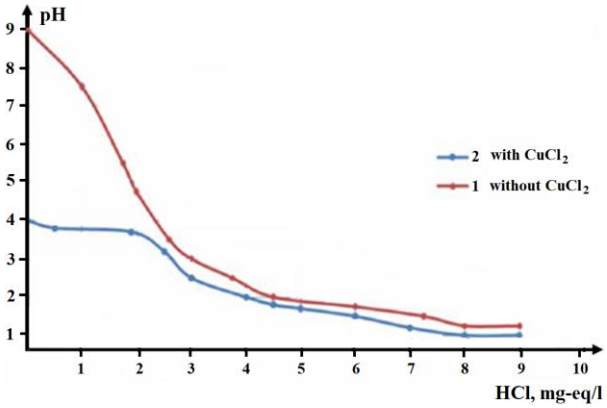


Figure 3. Potentiometric titration curves of the anionite

When the OH-form anionite comes into contact with NaCl and HCl solutions, the following reaction occurs:

$$\mathbf{R\text{-}NH_2OH + HCl \rightarrow RNH_2Cl + H_2O} \qquad (1)$$

In addition to NaCl and HCl solutions, when contacting solutions containing copper ions, an additional complex is formed, and after the first reaction it proceeds as follows:

$$\mathbf{R\text{-}NH_2OH \leftrightarrow RNH_2 + H_2O} \qquad (2)$$

$$\mathbf{R\text{-}NH_2 + CuCl_2 \leftrightarrow [Cu(RNH_2)_2]Cl} \qquad (3)$$

Under the action of acids, this complex decomposes according to the following reaction:

$$\mathbf{[Cu(RNH_2)_2]Cl + HCl \rightarrow CuCl_2 + RNH_2Cl} \qquad (4)$$

Since the H–N bond is stronger than the Cu–N coordination bond [2], the acid capacity of the anionite does not change. This is because, in both cases, one H^+ ion corresponds to one amino group. The proof of this is that the exchange capacity is the same in the first and second cases. It should be noted that under the experimental conditions, along with complex formation, a precipitation reaction also occurs:

$$\mathbf{Cu^{2+} + 2OH \leftrightarrow Cu(OH)_2} \qquad (5)$$

This is confirmed by the acidification of the solution: in this case, the pH of the equilibrium solutions is significantly lower than that observed for ion exchange alone. The following pattern is observed: the greater the amount of precipitate formed, the lower the pH value of the equilibrium solutions. In this case, when a precipitate is formed, an increase in the amount of precipitate leads to a decrease in the potentiometric titration curve, while complex formation itself is not reflected in the shape of the potentiometric titration curve.

The initial course of the potentiometric curve is decisively influenced by the pH value: the more precipitate is released, the lower the titration curve. It should be noted that the formation of complex compounds with metal ions, in particular with copper, occurs at significantly lower pH values of the equilibrium solutions than precipitation. The maximum uptake of copper by the obtained anionite occurs when the pH of the equilibrium solutions is 3.5–4. With a further increase in the pH of the equilibrium solutions, the amount of precipitate increases, and copper sorption decreases to some extent due to complex formation. This is related to the fact that the formed precipitate hinders the diffusion of copper ions to the ionogenic groups of the anionite and adheres firmly to the anionite granules [11].

Sorption on ion exchangers is widely used in industrial practice for the recovery of molybdenum from various solutions obtained during the processing of low-grade raw materials, as well as for the removal of molybdenum from different types of water. In this context, the investigation of new, convenient, import-substituting sorbents with sufficiently high basicity and selective properties toward molybdenum and tungsten is of great interest. Therefore, in order to determine the applicability of the synthesized anionites in molybdenum hydrometallurgy, it is of interest to study the dependence of molybdenum ion sorption on various factors using the synthesized anionites. The use of melamine containing a triazine ring as a raw material, according to literature data, promotes the selective uptake of molybdenum ions by anionites.

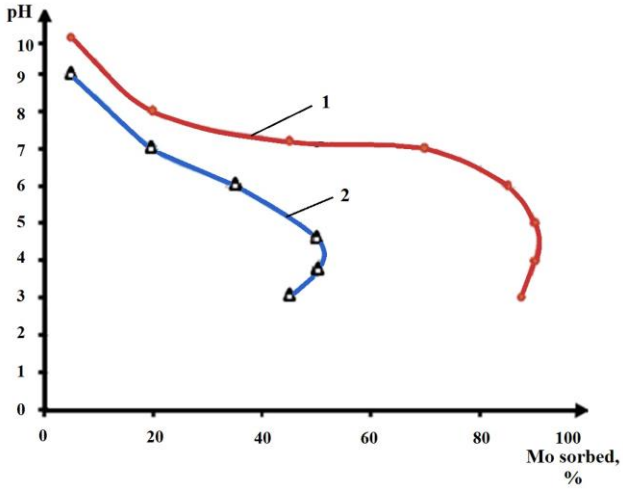


Figure 4. Effect of solution pH on molybdenum sorption (g/l).
1- synthesized anionite;
2 - AN-2F anionite.

The results obtained for molybdenum sorption on the synthesized anionite were compared with data for industrial anionites AN-2F and FAN, which are recommended for the recovery of molybdenum from industrial solutions. An ammonium molybdate solution with a concentration of $C_{initial}$ = 1 g/l was used as the model solution. The anionites were used in the OH^-, SO_4^{2-}, and Cl^- forms [12]. The obtained data show that molybdenum is better sorbed when the anionite is in the chloride form in a pure ammonium molybdate solution. In the presence of competing sulfate ions (48 g/l SO_4^{2-}), the synthesized anionite exhibits higher selectivity toward molybdenum ions, and its sorption properties remain practically unchanged at 292–256 mg/g; the presence of competing ions reduces the sorption capacity by only 10–12%.

Conclusion

The effects of pH and the concentration of competing ions on molybdenum sorption were studied. The results of these investigations are presented in Figure 4, and for comparison, data for the AN-2F anionite are also shown [13]. Analysis of the curves in Figure 4 shows that the maximum sorption of molybdenum is observed in the pH range of 3.2–5.0. Comparison of the data on molybdenum sorption by the synthesized anionite in the Cl^- and SO_4^{2-} forms indicates

that, in the Cl^- form, molybdenum sorption is somewhat reduced due to anion exchange between chloride and sulfate ions. In the SO_4^{2-} form, this phenomenon is not observed [14]. Based on the obtained results, it should be noted that the synthesized anionite, due to its sorption properties, can be used in molybdenum hydrometallurgy for the purpose of molybdenum recovery.

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IMPROVING NOVICE PROGRAMMING OUTCOMES IN UZBEKISTAN: A QUASI-EXPERIMENTAL STUDY OF THE IPRV INSTRUCTIONAL PROTOCOL

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Abstract. *Students entering higher education in Uzbekistan frequently begin programming courses with minimal prior exposure to formal computing concepts. In such contexts, conventional instruction—typically consisting of theoretical explanation followed by unstructured laboratory execution—often fails to support conceptual understanding among novice learners. This paper reports the classroom implementation and evaluation of the IPRV (Instruct–Predict–Run–Verify) pedagogical protocol, a structured instructional cycle designed to promote reasoning and reflection prior to code execution. The IPRV protocol was implemented over a four-month instructional period in undergraduate programming courses and evaluated using a quasi-experimental, non-equivalent groups design. Student performance in an intervention group taught using IPRV (n = 25) was compared with a control group receiving traditional instruction followed by laboratory execution (n = 28). Results indicate that student performance in the IPRV group was strongly associated with higher learning outcomes (Mann–Whitney U = 581.5, p < .001), with a large practical effect size (r = 0.57). Distributional and quartile analyses further suggest reduced performance disparity and improved outcomes among lower-performing students. While the instructional components of IPRV are individually well established, the contribution of this study lies in their mandatory sequencing, enforced prediction commitment, and empirical validation as a unified pedagogical protocol for novice programmers. The findings suggest that carefully constrained instructional design can meaningfully support introductory programming learning in contexts where students enter higher education with limited prior IT exposure. These results have immediate practical implications for curriculum developers and university instructors in Uzbekistan, offering a scalable, evidence-based strategy to enhance digital literacy and instructional quality in alignment with national education reforms.*

Keywords: *IT education reform, Novice programming pedagogy, Instructional scaffolding, Cognitive load theory.*

1. Introduction

Rapid advances in digital technologies have positioned programming literacy as a core competency within contemporary higher education systems. In Uzbekistan, national initiatives such as IT Park Uzbekistan and One Million Coders reflect a sustained policy effort to strengthen computational skills and align education with emerging labor market demands. International organizations, including UNESCO and UNICEF, have similarly emphasized the role of structured, accessible instruction in supporting digital education reform within the country (UNESCO, 2023; UNICEF, 2025).

Despite these initiatives, a persistent challenge remains at the university level: A substantial proportion of students begin university studies without prior hands-on experience in computer

programming. Although informatics is included in the secondary school curriculum, instructional depth and emphasis on conceptual reasoning vary considerably across institutions and regions. As a result, introductory programming courses frequently enroll students who lack foundational mental models of program execution and struggle to engage meaningfully with code.

In many university settings, introductory programming instruction follows a familiar pattern: theoretical explanation of syntax and constructs, followed by immediate execution of example programs in laboratory sessions. While this approach may suffice for students with prior exposure, it often proves insufficient for true beginners. Novice learners frequently rely on trial-and-error execution, using program output as a substitute for understanding rather than as evidence to evaluate prior reasoning. This tendency can lead to superficial learning, persistent misconceptions, and declining engagement.

This study examines an alternative instructional approach: the IPRV (Instruct–Predict–Run–Verify) pedagogical protocol. IPRV structures introductory programming instruction as a mandatory learning cycle in which students must first receive explicit instruction, then commit to predictions about program behavior before execution, and finally verify outcomes through guided reflection. Unlike instructional approaches in which prediction or reflection are optional, IPRV enforces these stages as non-negotiable components of learning.

The protocol was implemented continuously over a four-month period in undergraduate programming courses and evaluated under authentic classroom conditions. Rather than proposing a new learning theory, this study investigates whether a constrained and systematically sequenced instructional protocol is associated with improved learning outcomes for novice programmers. The findings contribute empirical evidence relevant to programming education in Uzbekistan and comparable contexts where students enter higher education with heterogeneous educational backgrounds and limited prior exposure to computing.

2. Computer Science Education in Uzbekistan

Computer science education in Uzbekistan has expanded considerably since independence, yet its development has been uneven across educational levels and regions. During the Soviet period, computing education was largely theoretical and restricted to specialized institutions. Following independence, informatics was introduced as a distinct subject within the national curriculum; however, the depth of programming instruction and emphasis on conceptual reasoning continue to vary widely (ResearchGate, 2024).

In recent years, the Uzbek government has placed renewed emphasis on digital education. National initiatives such as One Million Coders and the establishment of IT Park Uzbekistan reflect a policy commitment to developing practical IT skills and fostering industry–academia collaboration. Parallel efforts by international organizations have supported instructional innovation and teacher development. For example, UNICEF-supported technology-enhanced learning pilots and UNESCO-backed distance education initiatives during the COVID-19 pandemic demonstrated that structured, well-supported instruction can lead to measurable learning gains even in resource-constrained settings (UNESCO, 2024; UNICEF, 2025).

These initiatives highlight two themes relevant to the present study. First, effective learning outcomes in Uzbekistan have been associated more strongly with instructional structure and teacher guidance than with the introduction of advanced technologies alone. Second, pedagogical approaches must remain adaptable to institutional contexts characterized by heterogeneous student preparation and variable access to computing infrastructure.

The IPRV pedagogical protocol was developed within this educational landscape. By emphasizing explicit instruction, structured reasoning, and guided reflection, the protocol aligns with national priorities while addressing persistent challenges in introductory programming education at the university level.

3. Challenges for Novice Programming Learners

Learning to program presents well-documented challenges for novice learners, particularly those encountering formal programming concepts for the first time. Programming requires learners to coordinate abstract syntax, semantics, and execution flow—demands that impose a high intrinsic cognitive load on working memory (Sweller, Ayres, & Kalyuga, 2011). Without carefully designed instructional support, novice learners are prone to overload, resulting in fragmented understanding and persistent misconceptions.

Research in computer science education has shown that many beginners struggle to form accurate mental models of how programs execute, even after completing introductory courses (Robins, Rountree, & Rountree, 2003). In traditional instructional settings, students often move directly from explanation to execution, relying on trial-and-error approaches that prioritize producing output over understanding underlying logic. Such practices can mask misconceptions rather than resolve them.

Motivational factors further complicate novice learning. Early difficulties, repeated errors, and lack of formative feedback can reduce learner confidence and engagement. This pattern is particularly evident among students entering higher education without prior exposure to computing, a common situation in the Uzbek context. When execution becomes the primary learning mechanism, students may disengage cognitively, using program output as a proxy for understanding.

The IPRV pedagogical protocol was designed to address these challenges by restructuring how novices engage with code. By enforcing prediction commitment prior to execution and systematic verification afterward, IPRV seeks to promote deliberate reasoning, support mental model development, and reduce unproductive trial-and-error behavior. The protocol does not eliminate execution but situates it within a structured reasoning cycle that encourages deeper engagement with program behavior.

4. The IPRV Pedagogical Protocol

The IPRV (Instruct–Predict–Run–Verify) pedagogical protocol is a structured instructional cycle designed to support novice programming learners through mandatory sequencing and constrained engagement. Unlike loosely structured active-learning approaches, IPRV functions as an instructional protocol: each stage must be completed before progression to the next is permitted.

While instruction, prediction, execution, and reflection are individually familiar elements in programming pedagogy, the contribution of IPRV lies in their enforced integration and empirical validation as a single, repeatable learning cycle. The protocol was implemented consistently across all instructional units during the four-month study period.

4.1 Instruct

Each instructional cycle begins with explicit instructor-led instruction. During this stage, the instructor introduces programming concepts, syntax, and execution logic using short explanations and worked examples. The focus is on establishing a clear conceptual baseline rather than encouraging exploratory discovery.

This emphasis aligns with research demonstrating that novice learners benefit from guided instruction and modeling before engaging in independent problem-solving (Sweller et al., 2011).

In the IPRV classrooms, instruction was deliberately concise and concept-focused, avoiding unnecessary syntactic complexity that could increase extraneous cognitive load.

Importantly, instruction in IPRV is not treated as a sufficient learning activity on its own. Students are explicitly informed that understanding will be tested through reasoning and prediction rather than immediate execution.

4.2 Predict (Prediction Commitment)

Following instruction, students enter the Predict stage, where they are required to commit to a predicted outcome for a given code segment or problem scenario. Predictions are recorded explicitly before any execution is allowed.

This requirement distinguishes IPRV from instructional approaches in which prediction is optional, informal, or purely mental. By enforcing prediction commitment, the protocol ensures that all students externalize their reasoning and articulate expectations about program behavior.

Prediction-based activities have been shown to activate prior knowledge and expose misconceptions (Guzdial, 2010). In IPRV, the pedagogical value of prediction is strengthened by its mandatory nature: students cannot proceed without first engaging cognitively with the problem. This design increases learner accountability and reduces passive engagement.

4.3 Run

Only after predictions are recorded do students proceed to the Run stage, where they execute the code using a programming environment. Execution is deliberately delayed to prevent students from using output as a substitute for reasoning.

During execution, students are encouraged to observe program behavior carefully, noting intermediate values and control flow. Execution is framed as a means of testing prior reasoning rather than discovering answers through trial and error.

This separation of reasoning and execution is particularly important for novice learners, who are more susceptible to cognitive overload when multiple demands compete simultaneously for working memory resources (Sweller et al., 2011).

4.4 Verify

The Verify stage requires students to compare predicted outcomes with actual execution results. This comparison is conducted through guided discussion, instructor questioning, or structured reflection activities.

Verification serves as the reflective core of the protocol. Discrepancies between prediction and outcome prompt learners to identify faulty assumptions and revise their mental models. Errors are treated as diagnostic information rather than failures, reinforcing a learning-oriented classroom culture.

Research on novice programming consistently highlights the importance of immediate, structured reflection in supporting conceptual change (Robins, Rountree, & Rountree, 2003). By embedding verification as a mandatory stage, IPRV ensures that reflection is systematic rather than incidental.

5. Theoretical and Pedagogical Foundations of IPRV

The IPRV pedagogical protocol is grounded in established principles from cognitive psychology and computer science education. Rather than proposing a new learning theory, the protocol operationalizes existing research into a constrained instructional design suited to novice learners.

5.1 Cognitive Load Regulation

The abstract and symbolic nature of programming concepts places substantial intrinsic demands on novice learners' working memory. Cognitive Load Theory suggests that instructional design should minimize extraneous load to prevent working memory overload, particularly for novices (Sweller et al., 2011).

IPRV addresses this by sequencing tasks so that learners engage in one cognitive demand at a time: instruction precedes reasoning, reasoning precedes execution, and execution precedes reflection. This separation reduces cognitive interference and supports schema construction over repeated cycles.

5.2 Prediction, Commitment, and Conceptual Change

Research on prediction-based learning indicates that requiring learners to anticipate outcomes can activate prior knowledge structures and reveal underlying misconceptions (Guzdial, 2010). IPRV extends this principle by requiring prediction commitment, ensuring that learners actively engage with program logic rather than passively observing execution.

The commitment aspect is pedagogically significant. When learners compare predicted and actual outcomes, cognitive conflict becomes salient, increasing the likelihood of conceptual change. In contrast, unstructured execution—common in traditional laboratory settings—may allow misconceptions to persist unnoticed.

5.3 Constraint-Based Pedagogy for Novices

A defining characteristic of IPRV is its use of instructional constraints. Rather than maximizing learner freedom, the protocol deliberately restricts when execution can occur. Research suggests that such constraints can be beneficial for novices by discouraging unproductive strategies and focusing attention on core concepts (Sweller et al., 2011).

Within this framework, IPRV can be understood as a pedagogical protocol rather than a collection of activities. Its novelty lies in demonstrating that carefully designed instructional constraints—when applied consistently—are associated with improved learning outcomes in introductory programming contexts.

6. Methodology (Actual Implemented Study)

6.1 Research Design

This study employed a quasi-experimental, non-equivalent groups design to examine the association between the IPRV pedagogical protocol and student learning outcomes in introductory programming courses. Random assignment was not feasible due to institutional constraints; therefore, intact class sections were observed over a continuous four-month instructional period.

The study evaluates classroom practice under authentic conditions rather than testing a hypothetical intervention. The IPRV protocol was implemented from the first week of instruction in the intervention group, while the control group followed conventional instructional practices.

6.2 Participants

Participants were undergraduate students enrolled in introductory programming or computer science courses at a higher education institution in Uzbekistan. All participants were novice learners with limited prior exposure to formal programming.

- IPRV group (intervention): 25 students
- Control group: 28 students

Both groups followed the same syllabus, covered identical topics, and completed the same assessment.

6.3 Baseline Equivalence

To ensure comparability between groups, all students completed an entrance diagnostic test prior to the start of instruction. Analysis of diagnostic scores indicated no meaningful difference in baseline performance between the IPRV and control groups. This finding supports the assumption that observed differences in post-intervention performance are associated with instructional conditions rather than pre-existing disparities.

6.4 Instructional Conditions

IPRV Group

Students in the intervention group were taught using the IPRV (Instruct–Predict–Run–Verify) pedagogical protocol throughout the four-month period. Each instructional unit adhered to the same mandatory sequence:

1. Instructor-led explanation of concepts and examples
2. Student prediction with explicit commitment
3. Code execution
4. Guided verification and reflection

Progression between stages was enforced consistently across lessons.

Control Group

Students in the control group received conventional instruction, consisting of theoretical explanation followed by laboratory-based code execution. Prediction and structured verification were not systematically incorporated. Students typically executed code immediately after instruction.

6.5 Standardization of Instructional Conditions

To minimize instructional variability, both groups used:

- The same syllabus and learning objectives
- The same instructional materials and examples
- The same assessment instrument and grading rubric
- The same instructional duration and schedule

This standardization reduces the likelihood that differences in outcomes were attributable to curricular or assessment-related factors.

6.6 Assessment and Data Analysis

Learning outcomes were measured using a post-instruction assessment aligned with course objectives, with a maximum score of 30 marks. Score distributions were assessed for normality using the Shapiro–Wilk test; results indicated non-normal distributions. Consequently, the Mann–Whitney U test was used for group comparison, and rank-biserial correlation (r) was calculated as an effect size measure. Descriptive statistics and distributional analyses were also conducted.

7. Results

7.1 Descriptive Statistics

Descriptive statistics are summarized in **Table 1**. Students in the IPRV group achieved higher mean and median scores than those in the control group, with a mean difference of 9.27 marks—approximately 31% of the total assessment score.

Group	N	Mean	Median	SD	Min	Max
Control	28	14.57	16.00	5.83	2	25
IPRV	25	23.84	26.00	6.25	13	30

Table 1. Descriptive Statistics of Student Test Scores

Notably, the minimum score in the IPRV group exceeded the lower quartile of the control group, suggesting reduced extreme underperformance among students exposed to the IPRV protocol.

7.2 Inferential Analysis

Given the non-normal distribution of scores, a Mann–Whitney U test was used to compare performance between groups. The analysis revealed a statistically significant difference:

- U = 581.5
- $p < .001$

The corresponding effect size, calculated using rank-biserial correlation, was r = 0.57, indicating a large practical effect. This result suggests that the performance gains associated with the IPRV protocol are not only statistically reliable but educationally meaningful.

7.3 Distributional Patterns (Figure 1 and Figure 3)

Figure 1 (boxplot comparison) illustrates a clear upward shift in the score distribution for the IPRV group relative to the control group. The control group exhibits greater dispersion and lower outliers, whereas the IPRV group demonstrates a more compact distribution centered at higher scores.

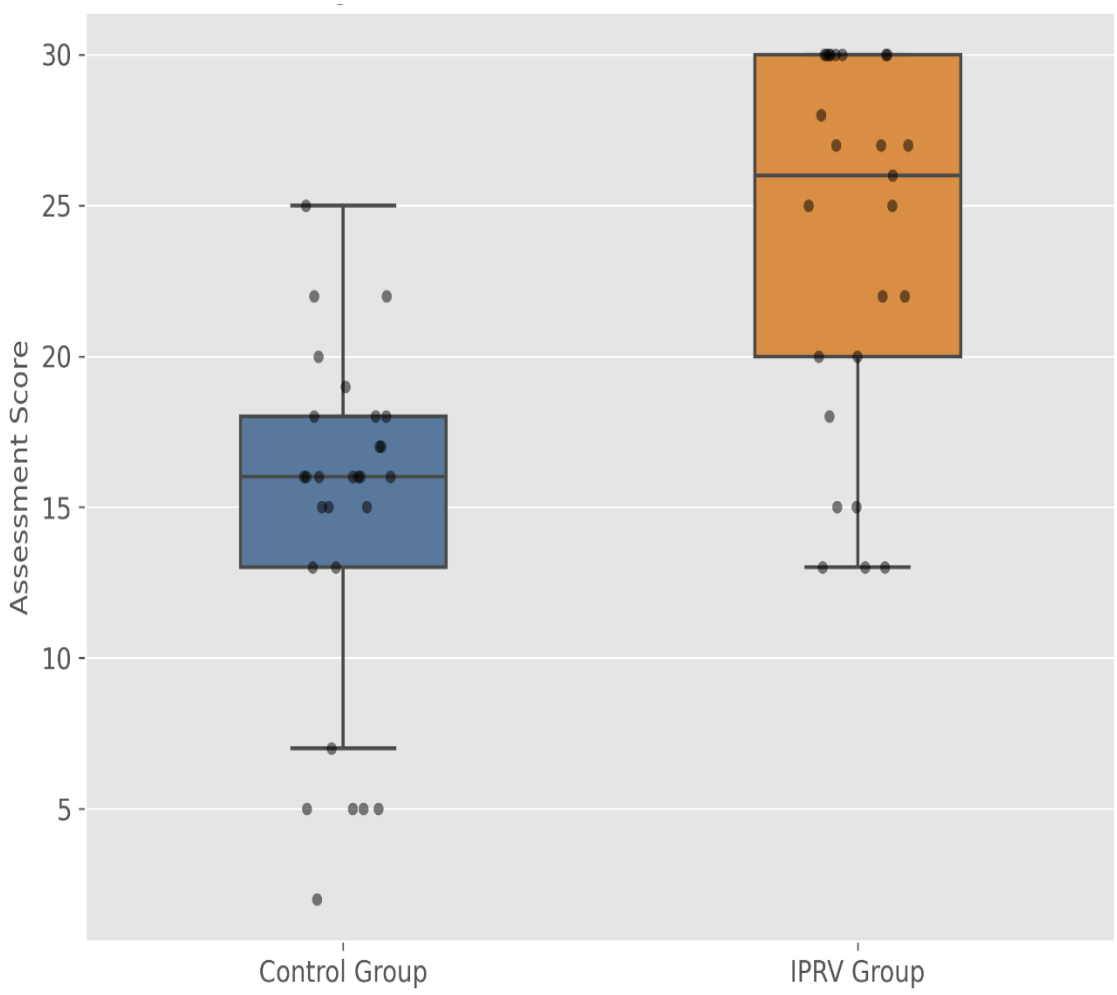


Figure 1. Boxplot Comparison of Post-test Scores

Figure 2 (histogram comparison) further highlights this pattern, showing that IPRV students are concentrated in higher score ranges, while control group scores are more widely spread across lower and mid-range values. These distributional differences suggest that the observed performance gains are not driven by a small subset of high achievers.

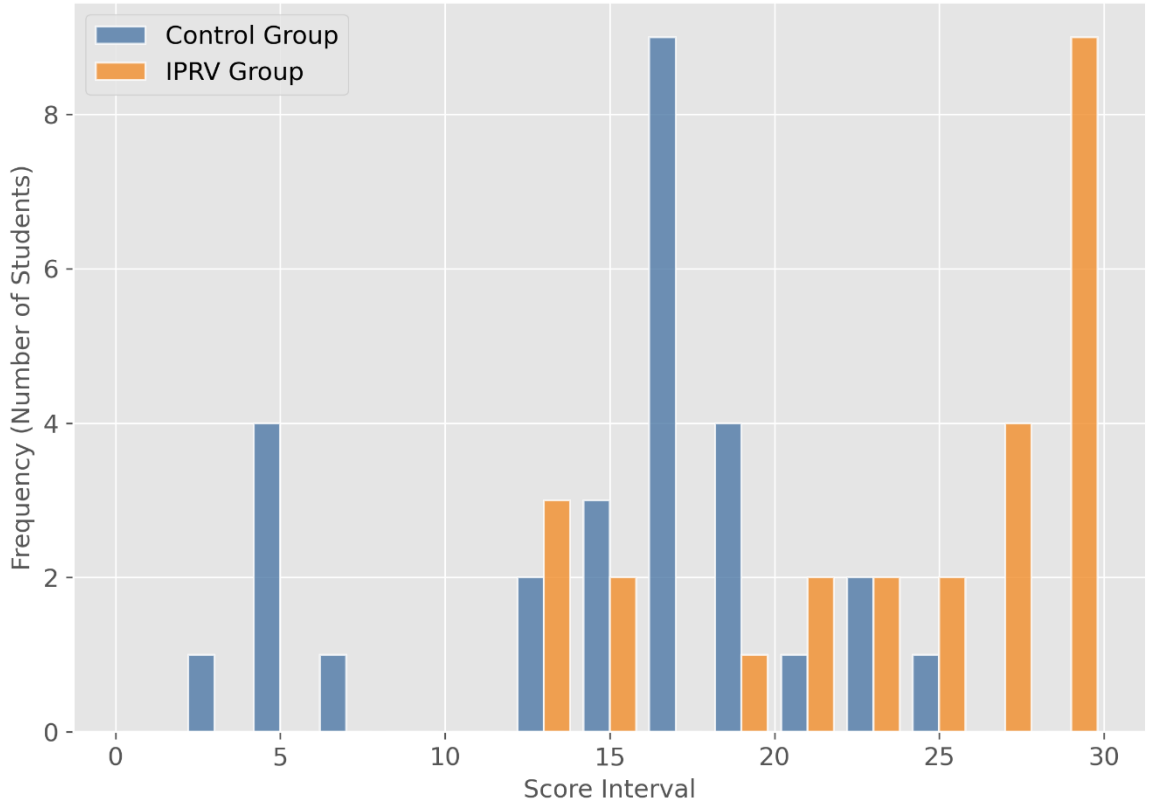


Figure 2. Frequency Distribution of Scores

7.4 Mean Scores and Confidence Intervals (Figure 3)

Figure 3 presents mean scores with 95% confidence intervals for both groups. The limited overlap between confidence intervals reinforces the robustness of the observed difference. The IPRV group's confidence interval lies entirely above that of the control group, indicating consistent performance advantages across the group.

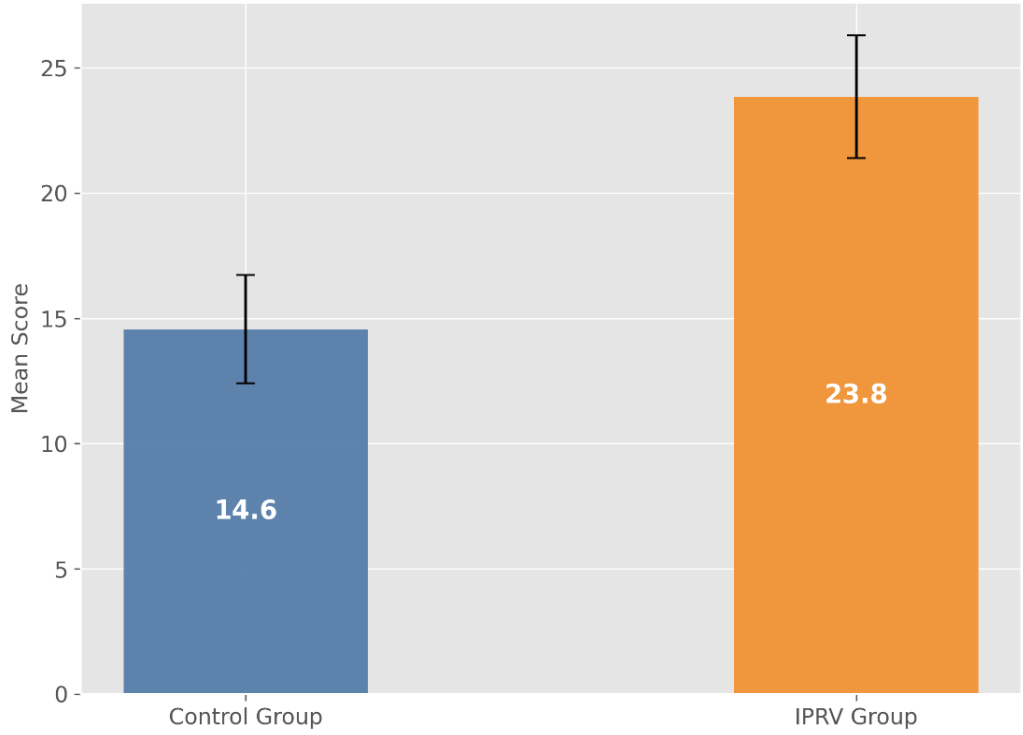


Figure 3. Mean Scores with Standard Error

7.5 Quartile and Equity Analysis (Figure 4)

Figure 4 compares quartile values for both groups and reveals a notable equity-related pattern: the first quartile of the IPRV group exceeds the median of the control group. This suggests that lower-performing students in the IPRV group achieved outcomes comparable to or better than average-performing students in the control condition.

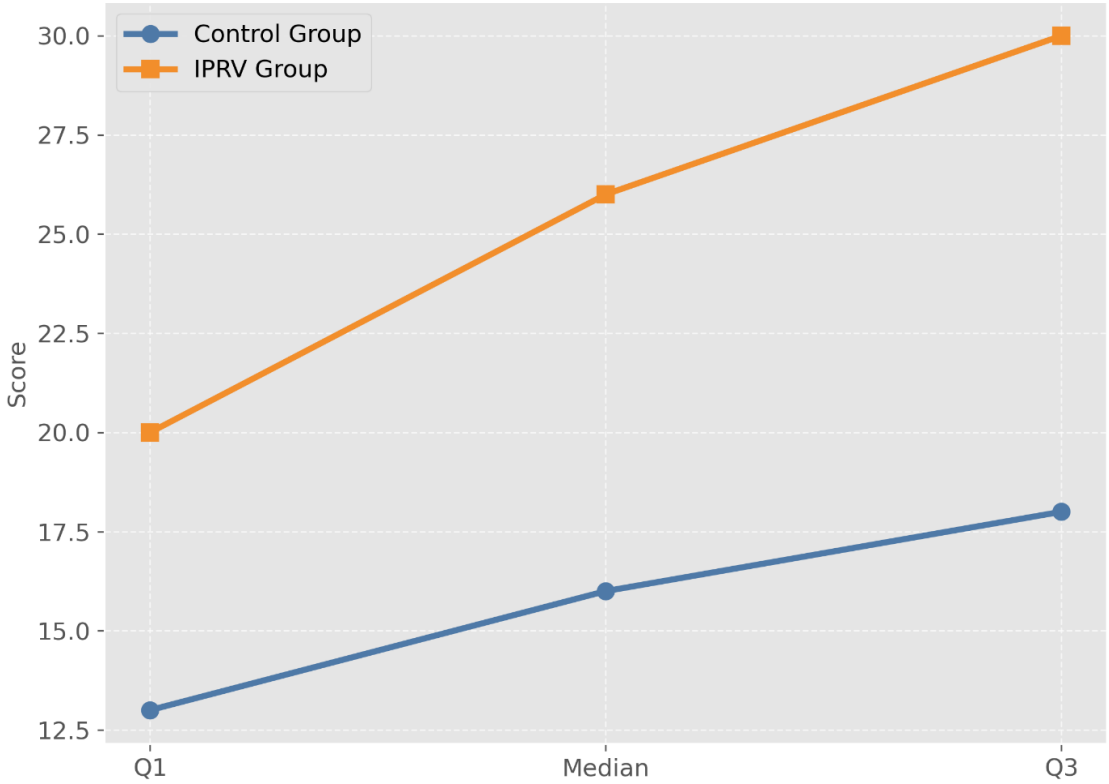


Figure 4. Quartile Comparison of Score Distributions

This pattern indicates that the IPRV protocol is associated not only with higher overall performance but also with reduced performance disparity among novice learners.

7.6 Summary of Findings

Across descriptive, inferential, and distributional analyses, the results consistently show that implementation of the IPRV protocol was strongly associated with improved learning outcomes over the four-month instructional period. The convergence of multiple analytic perspectives strengthens confidence in the robustness of these findings.

8. Discussion and Implications

The results of this study indicate that implementation of the IPRV (Instruct–Predict–Run–Verify) pedagogical protocol was strongly associated with improved learning outcomes for novice programming students over a four-month instructional period. The observed differences between the IPRV and control groups were statistically significant and accompanied by a large practical effect size, suggesting that the protocol has meaningful educational relevance.

A central implication of these findings is the importance of instructional sequencing and constraint in novice programming education. Unlike the control condition—where students typically progressed from instruction directly to execution—the IPRV protocol required learners to commit to predictions before running code and to explicitly verify outcomes afterward. This sequencing appears to shift execution from a trial-and-error activity to a mechanism for testing prior reasoning.

Distributional analyses further suggest that the benefits of IPRV extend beyond high-performing students. The elevation of lower quartile scores and the reduced spread of outcomes

indicate that the protocol may help mitigate performance disparities commonly observed in introductory programming courses. This equity-oriented pattern is particularly relevant in the Uzbek higher education context, where students enter university with diverse educational backgrounds and varying levels of preparation.

From a pedagogical perspective, the findings support the view that constraint-based instructional design can be beneficial for novice learners. While flexibility and open-ended exploration are often emphasized in advanced learning contexts, this study suggests that beginners may benefit from more structured engagement that prioritizes reasoning and reflection before execution.

At an institutional level, the IPRV protocol offers a practical and scalable instructional approach. Its implementation does not require specialized software or additional technological resources, making it suitable for a wide range of higher education settings. For universities in Uzbekistan and similar contexts, IPRV provides an evidence-informed method for strengthening introductory programming instruction without substantial infrastructural investment.

9. Conclusion and Future Work

This study examined the classroom implementation of the IPRV (Instruct–Predict–Run–Verify) pedagogical protocol in introductory programming education for novice learners in Uzbekistan. The findings indicate that the protocol was associated with significantly higher learning outcomes compared to conventional instruction followed by laboratory execution.

Rather than advancing a new learning theory, this study contributes by formalizing and empirically examining a constrained instructional protocol implemented in authentic classroom settings, that reshapes how novice learners engage with programming tasks. By enforcing prediction commitment prior to execution and systematic verification afterward, IPRV promotes deliberate reasoning and supports the development of accurate mental models.

Importantly, this paper focuses on the pre-productive phases of novice learning, emphasizing conceptual understanding before independent code creation. Future research will extend this work by examining how learners transition from verification to guided and independent program construction, including the design and evaluation of additional scaffolding phases that support productive coding without overwhelming beginners.

Within the context of Uzbekistan’s ongoing educational reforms, the IPRV protocol offers a practical, evidence-informed approach for improving introductory computer science education. More broadly, the study suggests that carefully designed instructional constraints can play a valuable role in supporting novice learners in cognitively demanding domains.

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TECHNOLOGICAL PROCESSES FOR THE REPAIR OF PLAIN BEARINGS OF INTERNAL COMBUSTION ENGINES BASED ON A MODERN APPROACH

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Abstract. *This article presents an in-depth analysis of wear processes occurring in plain bearings (liners) of internal combustion engines (ICEs), their causes, and their impact on performance. The types of abrasive, adhesive, fatigue, and corrosive wear observed on bearing surfaces are studied from a mechanical and tribological perspective. Modern technologies used for reconditioning worn bearings are also analyzed, and an improved repair method is developed. The proposed method improves engine reliability, extends its service life, and reduces operating costs.*

Keywords: *internal combustion engine, plain bearing, wear, tribology, repair technology, reconditioning.*

Introduction

It is widely accepted that internal combustion engines are one of the primary power sources for modern transport and industrial equipment. Reliable and long-term engine operation largely depends on the condition of its bearing components, particularly the plain bearings. These bearings support the load on the crankshaft and connecting rod journals and ensure rotation with minimal friction. The energy generated in the combustion chambers of an internal combustion engine's cylinders is used as a friction bearing for the connecting rods that rotate the crankshaft. It is important to note that because the rotational speeds and loads in this system are extremely high, friction within the components must be drastically reduced. Otherwise, the engine will fail very quickly. To reduce friction, all critical contact surfaces within the engine are surrounded by a micron-thick layer of oil formed by a specialized lubrication system.

However, many aspects of friction and wear processes at contact surfaces remain poorly understood. When surfaces rub, mechanical, electrical, thermal, and chemical processes occur simultaneously. Friction can harden or soften metal, increase or decrease its carbon content, saturate or dehydrate it, convert gold and platinum into oxides, and polish or weld the surfaces of components. Friction is a complex, self-organizing process in which systems are formed that deliberately and in a specific sequence damage the surface or, conversely, reduce wear. Despite the high level of solutions for calculating the strength, rigidity, and priority of machine components, the current state of friction and wear theory does not allow designers to reliably predict the wear resistance of adjacent surfaces. In particular, despite the fact that more than a century has passed since its development, calculations based on hydrodynamic lubrication theory do not possess the same accuracy and reliability as calculations performed using material resistance methods, which assume a constant oil film between the rubbing surfaces.

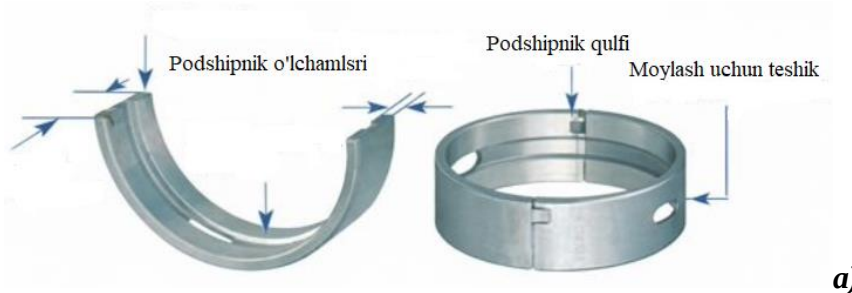
In the future, increasing the service life, productivity, and performance of machines and mechanisms depends largely on how positively and completely tribological issues are resolved. Therefore, in recent years, leading designers, technologists, and scientists from various fields

worldwide have been striving to solve tribological problems. As a result, machine service life is extended not only through rational design, technological, and operating conditions, but also through the development of a comprehensive theory of friction, wear, and lubrication based on advances in physics, chemistry, and materials science. In particular, the discovery of hydrogen wear laws opens up new possibilities for increasing the wear resistance and reliability of machine parts subject to friction.

Friction in bearings, gears, and piston systems leads to wear of the contact surfaces and energy loss. Therefore, friction in this context is considered a harmful factor. In brakes and clutches, as well as in friction and belt drives, it is beneficial to maintain an operating mode in which the friction force increases to a certain value without exceeding permissible wear limits. The correct selection of friction pair materials and oil type, as well as the adaptation of the design of the friction parts to operating conditions, determine the efficiency of the mechanisms and help improve the durability and reliability of the friction structure.

It is necessary to note that method is being developed to prevent complete wear of the original component material by creating new self-organizing structures on the surface of friction parts based on the laws of synergy. Tribological problems are currently being widely studied at factories and enterprises, universities, and research institutes. Scientific and practical conferences are held, and monographs and numerous articles are being published. A large body of theoretical and practical research has accumulated test results and observations on improving the wear resistance and reliability of friction machine parts.

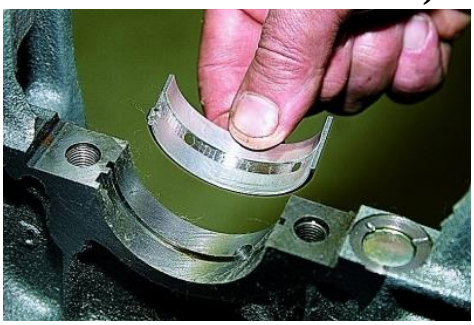
This oil film surrounding metal parts forms only under sufficiently high oil pressure. It is between the crankshaft journal and the bearing that this oil "layer" forms, dramatically reducing friction. Thus, camshaft bearings act as a protective element that protects one of the most important engine components—the camshaft—and significantly extends its service life. During operation, plain bearings undergo various wear processes as a result of high loads, poor lubrication conditions, increased temperature, and external contamination. This can lead to loss of engine power, increased vibration, and serious malfunctions. Therefore, identifying wear processes, analyzing them, and developing effective restoration technologies are urgent scientific and technical challenges.



a)



b)



c)



d)

Figure 1. Plain bearings: a – dimensions, b, d – bearing wear rate, c – location.

Wear processes occurring in plain bearings include abrasive, adhesive, fatigue, and corrosive (Table 1). Wear occurs when solid particles (dust, metal debris) enter the engine oil. This process scratches the bearing surface, reducing the thickness of its working layer (Figure 1).

Adhesive wear occurs when surfaces are in direct contact with each other under conditions of insufficient oil film. This results in microwelding and material migration. It is essential to mention that under the influence of repeated alternating loads, microcracks form in the bearing material, which over time lead to migration of the protective layer. Chemical corrosion occurs on the bearing surface under the influence of fuel combustion products and aggressive substances. This situation is especially accelerated by the use of low-quality oils.

Table 1. Main types of wear in plain bearings

	Type of food	Reasons	Consequences
1	Abrasive	Solid particles in oil	Surface scratches, increased clearance
2	Adhesion	Insufficient oil film	Material transfer
3	Fatigue	Reload	Cracks and coating failure
4	Corrosion	Chemically aggressive environment	Surface erosion

The wear determination process for plain bearings is as follows:

Engine → Bearing → Visual Inspection → Measurement → Oil Analysis → Conclusion.

Plain bearing wear is determined by the following methods:

1) visual and microscopic inspection;

2) determining radial clearance using measuring instruments;

3) detecting metal particles during oil analysis;

4) vibration diagnostics and acoustic monitoring.

These methods allow for an accurate assessment of the degree of wear and the selection of a repair strategy. Currently, the following technologies are widely used for bearing refurbishment:

1) remelting of antifriction coatings (babbitting);

2) plasma and thermal spray coatings;

3) restoration with polymer-composite materials;

4) laser surface hardening technologies.

These methods are used to restore the bearing's working surface and extend its service life. This article proposes the following improved process sequence for plain bearing repair:

1. Complete disassembly and cleaning of the bearing;
2. Diagnosis of the type and degree of wear;
3. Mechanical and chemical preparation of the working surface;
4. Application of a modern antifriction coating;
5. Final treatment and control measurements;
6. Testing and commissioning.

The proposed technology improves engine reliability and reduces repair costs. There are several effective methods for restoring plain bearings based on modern bearing repair technologies (Table 2).

Table 2. Bearing Reconditioning Technologies

Technology	Scope	Advantage
Babbitt	Classic bearings	Cheap and reliable
Plasma coating	High load	Solid surface
Polymer coating	Light engines	Low friction

Technological card of the repair process (Table 3).

Table 3. Technological card of the repair of a sliding bearing

Stage	Action	Equipment	Result
1	Disassembly and cleaning	Washing machine	Clean detail
2	Diagnostics	Micrometer	Eating is determined
3	Provide coverage	Plasma device	Surface is restored.
4	Final processing	Machine tool	Ready-made bearing

Conclusion

It can be concluded that the proposed technological approach extends the service life of plain bearings, improves engine reliability, and reduces repair costs. Wear processes occurring in the plain bearings of internal combustion engines have a significant impact on overall engine efficiency. Their timely detection and restoration using modern technologies significantly increases engine life. The developed repair method is practically effective and can be widely implemented in service and repair facilities.

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DEVELOPMENT OF AN INTELLIGENT MEASUREMENT AND MONITORING SYSTEM BASED ON ESP32 AND SEMICONDUCTOR SENSORS

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Abstract. *This paper presents the development of an intelligent measurement and monitoring system based on the ESP32 microcontroller integrated with semiconductor sensors. The proposed system is designed to collect, process, and transmit real-time environmental and physical parameter data using modern Internet of Things (IoT) technologies. The ESP32 microcontroller was selected due to its high performance, low power consumption, and built-in wireless communication modules. Semiconductor sensors were used to measure parameters such as temperature, humidity, gas concentration, and air quality. Experimental results demonstrate that the developed system provides high measurement accuracy, stable data transmission, and efficient real-time monitoring. The proposed solution can be applied in smart homes, industrial monitoring, environmental control, and healthcare systems.*

Keywords: *ESP32, semiconductor sensors, intelligent measurement system, IoT, monitoring, real-time data.*

Introduction

In recent years, the rapid development of microcontroller technologies and sensor systems has significantly expanded the possibilities of intelligent measurement and monitoring systems. The increasing demand for real-time data acquisition, remote monitoring, and automated control has led to the widespread adoption of Internet of Things (IoT)-based solutions in various fields, including smart homes, industrial automation, environmental monitoring, and healthcare. Traditional measurement systems are often limited by low flexibility, lack of real-time data processing, and insufficient communication capabilities. In contrast, modern intelligent systems integrate microcontrollers, semiconductor sensors, and wireless communication modules to ensure accurate measurements, data analysis, and remote access. Among various microcontrollers, the ESP32 stands out due to its dual-core processor, low power consumption, integrated Wi-Fi and Bluetooth modules, and high compatibility with various semiconductor sensors. These features make the ESP32 an ideal platform for developing compact and energy-efficient intelligent monitoring systems. This research aims to develop an ESP32-based intelligent measurement and monitoring system integrated with semiconductor sensors, capable of real-time data acquisition, processing, and wireless transmission. The main objective of this work is to design the system architecture, implement sensor data processing algorithms, and evaluate the system's performance through experimental testing.

Materials and methods. System Architecture. The proposed intelligent measurement and monitoring system is designed as a modular and scalable platform based on the ESP32

microcontroller and semiconductor sensors. The overall system architecture ensures reliable data acquisition, real-time processing, and wireless transmission to a remote monitoring environment. The system consists of the following main components:

- ESP32 microcontroller unit
- Semiconductor sensors for measuring temperature, humidity, gas concentration, and air quality
- Signal conditioning circuits and power supply module
- Wireless communication interface based on Wi-Fi technology
- Data visualization and monitoring platform (web or mobile application)

The ESP32 microcontroller acts as the central processing unit of the system. It is responsible for initializing sensors, acquiring raw measurement data, processing signals, and transmitting the processed information to a remote server. The selection of ESP32 is justified by its high computational performance, integrated Wi-Fi module, low power consumption, and compatibility with a wide range of digital and analog sensors. Signal conditioning circuits are used to ensure stable sensor operation and to adapt sensor output signals to the acceptable voltage levels of the ESP32 analog-to-digital converter (ADC). A regulated power supply module provides stable voltage to all system components, which is essential for accurate and reliable measurements.

Semiconductor Sensors. Semiconductor sensors were selected as the primary sensing elements due to their high sensitivity, compact dimensions, fast response time, and low energy consumption. These characteristics make them suitable for intelligent monitoring systems operating in real-time environments. The system measures the following physical and environmental parameters:

- ✓ **Temperature and humidity**, which are critical indicators of environmental conditions
- ✓ **Gas concentration**, reflecting the presence of harmful or combustible gases
- ✓ **Air quality indicators**, used to assess overall environmental safety and comfort levels

Depending on the sensor type and output characteristics, different communication interfaces were employed. Analog sensors were connected to the ESP32 through its built-in ADC channels, while digital sensors utilized communication protocols such as GPIO, I2C, or UART. This flexible interface selection allows the system to integrate various sensor types without significant hardware modifications. Before data acquisition, each sensor underwent an initial calibration process to minimize systematic errors and improve measurement accuracy. Calibration coefficients were stored in the ESP32 memory and applied during real-time data processing.

Data Processing Algorithm. Sensor data acquisition was performed at predefined and configurable time intervals. The ESP32 microcontroller continuously reads raw signals from all connected sensors and processes them using embedded software algorithms. To improve measurement accuracy and system stability, raw sensor data were subjected to digital filtering techniques, including noise reduction and signal smoothing. Calibration algorithms were applied to convert sensor output values into standardized physical units, such as degrees Celsius, percentage of relative humidity, or parts per million (ppm). After processing, the data were packaged into structured data frames and transmitted via Wi-Fi to a remote monitoring platform. The data processing and transmission workflow consists of the following sequential steps:

1. Sensor initialization and system startup

2. Sensor calibration and parameter configuration
3. Periodic data acquisition from all sensors
4. Digital filtering and normalization of raw signals
5. Conversion into physical measurement units
6. Wireless data transmission and storage on the server
7. Visualization and real-time monitoring through the user interface

This algorithmic structure ensures reliable operation, low latency, and efficient use of system resources.

Experimental Setup. Experimental tests were conducted under controlled laboratory conditions to evaluate the performance of the developed system. The experimental setup included reference measuring instruments to compare sensor readings and assess measurement accuracy. The system performance was evaluated based on the following criteria:

- Measurement accuracy and repeatability
- System response time
- Power consumption during continuous operation
- Stability and reliability of wireless data transmission

Each parameter was measured over extended operating periods to assess system robustness and long-term stability. The experimental results obtained from these tests were used to validate the effectiveness of the proposed intelligent measurement and monitoring system.

Results

The experimental results demonstrate that the developed ESP32-based intelligent measurement and monitoring system operates reliably and provides accurate and stable measurements under laboratory conditions. Throughout the experimental period, the system maintained continuous operation without hardware or software failures, confirming the robustness of the proposed architecture. Temperature and humidity measurements showed high accuracy when compared with reference measuring instruments. The observed deviation remained within an acceptable error range, indicating effective sensor calibration and signal processing. The consistency of temperature and humidity readings over time confirms the stability of both the semiconductor sensors and the ESP32 analog-to-digital conversion process.

Gas concentration and air quality sensors exhibited stable and repeatable responses under varying environmental conditions. Changes in gas concentration levels were reflected promptly in the sensor output, demonstrating a fast response time and adequate sensitivity. No abrupt signal fluctuations or long-term drift were observed during continuous operation, which indicates reliable sensor performance and effective noise filtering algorithms. Wireless data transmission via the integrated Wi-Fi module of the ESP32 was tested during prolonged monitoring sessions. The results showed stable communication with the remote server, and no significant data loss or transmission delays were detected. This confirms the suitability of the ESP32 for real-time monitoring applications that require continuous data exchange. The received data packets maintained integrity, and the transmission latency remained within acceptable limits for monitoring purposes. Power consumption analysis revealed that the system operates with relatively low energy usage, even during continuous sensing and data transmission. This characteristic makes the developed system suitable for long-term deployment, including applications powered by batteries or energy-efficient power sources. The low power consumption is primarily attributed to the efficient architecture of the ESP32 microcontroller and optimized data acquisition intervals. Graphs and data logs obtained during experimental testing provide visual

confirmation of the system's performance. Time-series plots of temperature, humidity, and gas concentration data illustrate smooth and continuous trends without unexpected anomalies. These results confirm that the system can successfully perform real-time monitoring and data visualization, enabling users to observe environmental changes dynamically through the monitoring platform. Overall, the experimental results validate the effectiveness of the proposed ESP32-based intelligent measurement and monitoring system in terms of accuracy, stability, wireless reliability, and energy efficiency.

Discussion. The results indicate that integrating semiconductor sensors with the ESP32 microcontroller enables the development of efficient and flexible intelligent measurement systems. Compared to traditional systems, the proposed solution offers enhanced functionality, including real-time data processing, remote monitoring, and scalability. The use of ESP32 significantly simplifies system design by eliminating the need for external communication modules. However, sensor calibration and environmental interference remain critical factors affecting measurement accuracy. Future improvements may include advanced data analysis techniques, cloud-based data processing, and machine learning algorithms for predictive monitoring.

Conclusion. In this study, an ESP32-based intelligent measurement and monitoring system integrated with semiconductor sensors was successfully developed and tested. The system provides accurate measurements, reliable wireless communication, and efficient real-time monitoring. The proposed solution can be applied in various domains, including smart homes, environmental monitoring, and industrial automation. Future work will focus on enhancing data analytics and expanding system functionality.

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VR AND MODERN TECHNOLOGIES

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Abstract. *Modern libraries are institutions operating on the basis of information technologies. Searching, storing, transmitting and delivering information to the user in a convenient way is one of the main tasks for today's libraries. Virtual reality (VR) technology and modern technologies - artificial intelligence (AI), Internet of Things (IoT), big data (Big Data), augmented reality (AR) - are taking library systems to a new level. This article will highlight methods for improving the efficiency of services by integrating VR and modern technologies into library activities and will consider the integration of VR devices with some modern technologies.*

Keywords: *library, VR technology, artificial intelligence, AR technology, Big Data, IoT, 3D environment, ARM, virtual library, virtual robot.*

INTRODUCTION

With the development of science, the technologies that interest, amaze and attract people are also changing. The role of information resource centers in increasing the scientific potential of students is invaluable. If we leave the IRCs in their traditional form without modernizing them, the interests of young people seeking knowledge may be diverted to other modern games, messengers, and entertainment programs. In this case, the mental abilities of the future generation may decrease. Therefore, it is important to establish modern libraries that are competitive with, if not superior to, the above. What is a modern library? By modern library we mean libraries integrated with modern technology devices, both real and virtual.

Therefore, increasing students' interest in ARs by applying modern technologies to the library is an urgent problem. To solve this problem, it is necessary to first study the current situation, study the technical characteristics of modern technologies necessary for ARs, and check the virtual state of the library. After these works are completed, programs that integrate modern technology and artificial intelligence will be created and implemented to develop library activities. We will mainly consider VR technologies as the main device and consider the integration of other technologies with it. Below are a few suggested methods that can increase both real and virtual library visits by students and readers and make the work of library staff much easier.

Literature review:

The use of modern technologies in IRC has been shaped by each era, depending on its own conditions. This can be found in the works of Slater, M. , Sanchez -Vives, MV “Enhancing learning through virtual reality” (2016) and Radianti, J. et al. “A systematic review of immersive virtual reality applications for higher education” (2020). These works provide a profound insight into the importance of VR in education. They demonstrate that VR can enhance learning by creating immersive experiences. Libraries, when used as learning centers, can capture users' attention and enhance their learning.

The use of VR technology in libraries is discussed in Ballard , M.'s article “Virtual Reality in Libraries: Emerging Trends and Best Practices” (2018). This resource provides guidance on practical aspects of VR use in libraries, such as virtual tours, historical simulations, and ways to

organize VR training courses. Particular attention is paid to enriching the user experience. Additionally, public libraries are also using VR tools as a means of engaging a youth audience.

the integration of artificial intelligence (AI) and libraries, see Cox , A.M., Pinfield, S., & Rutter, S. “AI, machine learning and libraries: A review of the literature and implications for LIS professionals” (2019) and Zhang, Y. “AI-Powered Library Services” (2021). AI is being used in libraries to provide services to users through recommendation systems, content indexing , and chatbots. If AI is integrated with a VR platform, users can easily find the necessary resource within a virtual library using AI.

On the use of cloud technologies and library infrastructure. Ramasamy, M. “Cloud Computing in Library Services” (2017) contains information. With the help of cloud services (Dropbox, Google Drive, institutional repositories), libraries can digitize their collections and easily connect them to a VR platform. Cloud technology is an important tool in delivering VR content to a broad user base.

On the work being carried out in Uzbekistan and Central Asia, the Ministry of Innovative Development of the Republic of Uzbekistan Information Resources and Digital Strategies of the National Library of the Republic of Uzbekistan (2021–2025) and R. Gaybullayev, N. Nazarov. Useful information can be obtained from the books “Information Library Technologies” . These books focus on the issues of digitization and electronic libraries in local literature, but VR has not yet been widely studied. Since this topic has not yet been fully researched, the VR library project attracts attention as an innovative initiative in Uzbekistan.

Literature shows that VR technology can significantly innovate library activities. By combining AI, cloud technology, and AR, a virtual library ecosystem can be created. Since this area is still in its infancy in Uzbekistan, there is great potential for scientifically-based projects.

The main part.

VR + AR (Augmented Reality) integration.

Integrating VR (Virtual Reality) and AR (Augmented Reality) technologies into library activities will allow you to provide innovative services to readers and users using modern digital capabilities. Below are ways to develop library activities using VR and AR technologies:

a) Interactive presentations and tours

Virtual library tour via VR: Library users can virtually tour different sections of the library, archive collections or historical buildings using VR glasses . Enriching the learning environment via AR: QR codes or AR symbols are placed on book covers and when the user scans them with their phone camera, 3D images, videos or audio descriptions appear.



b) Making the learning and teaching process interactive

will have the opportunity to view events in 3D scenes through VR. Interactive interaction with books through AR: You can make the reading process more interesting by adding AR animations to children's books.



c) Opportunities for users with special needs the blind: Books can be listened to and controlled through an audiobook interface using special VR apps. Enlarge or translate characters via AR: For users who have difficulty reading texts, the mobile app can enlarge the text or translate it into a language.

d) Preservation of cultural heritage and archives and presentation of historical library exhibits through VR : Rare manuscripts or ancient exhibits are digitized and preserved in a VR environment and exhibitions are organized. Live interpretation of archival documents through AR: Presenting documents interactively through AR , enriched with annotations and historical context.



Expected benefits

- Students' interest increases, and the learning process becomes simpler.
- Libraries will become centers of innovative technologies.
- The user experience will improve, especially for young people and students.
- Inclusive services will be created for groups with special needs.
- Digital archiving and long-term preservation of library resources will be ensured.

Practical steps

- Choosing VR/AR platforms (Google Expeditions, Unity, Vuforia, Meta Quest , etc.).
- Training of specialists: Training for library staff.
- Start a pilot project: Create multiple interactive library zones.

- To study user feedback and improve the service.
- Raising funds through local and international grants .

VR and Big Data Integration

Libraries can leverage Virtual Reality (VR) and Big Data technologies to transform from traditional book storage centers into modern, interactive knowledge centers. This integration provides users with a personalized experience, efficient resource management , and innovative learning opportunities.

a) Personalized Book Recommendation System (Big Data + VR). Goal: To automatically recommend books to users that match their interests and reading habits. AI develops recommendations based on users' book choices, search history , and ratings. This information is transmitted to library managers. ARM employees place recommended books on users' personal bookshelves based on statistical results . This work is done through the human factor. It provides visual reports for library administrators on the most searched books and user trends. It plans the library's operations using the data obtained. Big Data analytics is important in this.

b) Intelligent Management and Monitoring of Library Resources (Big Data). The goal of this integration is to effectively manage library collections and optimize resource utilization. The movement of books is monitored. Data is collected on which books are rented the most and how long they are kept.

RFID and Big Data can be used to track the status and location of books. Using the information obtained, it is possible to conveniently place literature . By analyzing user flows and optimizing working hours, library activity statistics can be generated .

d) Strengthening Inter-Library Collaboration (VR + Big Data). By combining the resources of different libraries, it will be possible to create a global knowledge network . Through the network of virtual libraries, users will have the opportunity to access the collections of libraries in other countries via VR. Joint projects can be carried out and virtual exhibitions and literary festivals can be organized by several libraries.



Useful Results:

- User convenience – personalized recommendations and virtual access.
- optimal allocation of books, rooms , and staff.
- Global knowledge exchange – research and collaboration opportunities without limits.
- New generation libraries – transforming traditional libraries into high-tech knowledge centers.
- VR and Big Data gives libraries the opportunity to develop not only as book storage centers, but also as interactive innovation centers.

Enhancing Library Operations Through VR and IoT Integration

IoT (Internet of Things) is a technology that enables various devices, sensors, and systems to be connected via the Internet, exchange information, and be intelligently controlled. The combination of Virtual Reality (VR) and IoT offers great opportunities to reimagine libraries based on modern technologies. This integration allows libraries to provide interactive, automated, and personalized experiences for their users.

a) Smart Book Cataloging and Search System (IoT + VR)

The goal of this system is to create the ability to quickly and easily find books. By installing a sensor on each book, its location and condition are monitored in real time. A VR navigation system is created, which shows users the exact location of the book on the library map using VR glasses or a mobile application. An automatic book return system is created . In this case, when a book is returned, it is automatically rewritten to the catalog via IoT.

b) Virtual Library Environment and Remote Access (VR + IoT)

Allows users to access library resources without leaving home. To do this, we need to build a VR library platform. Users will be able to enter the virtual library and view books in 3D , read them or rent them. IoT-based access control will be created. Users' personal information and membership status will be verified via IoT and access to the virtual library will be granted. Real-time data exchange will be monitored via IoT, and user actions in the virtual library (book selection, search) will be recorded in the real library system.

c) Intelligent Library Environment Management (IoT)

Making the library building energy-efficient and user-friendly is becoming increasingly important in today's world. We are implementing a smart lighting system. The IoT sensor adjusts the lighting based on the number of people in the room. Noise monitoring is also important. A special device is installed to monitor the noise level in the library and send an alert when necessary.

b) Library Security and Control (IoT)

Various viral attacks can be carried out by visiting a virtual library through VR. Preventing this will determine the future of the library. It is useful to prepare additional internet-connected devices and applications to protect library resources from theft and damage. Security checks and sensors – detect suspicious activity and send alerts. Allows access only to authorized users through virtual and automatic door control.

Useful Results:

- Convenience for users - quick finding of books, virtual access from home.
- Efficient use of resources – optimal distribution of books and rooms.
- Energy saving – reducing costs through smart control systems.
- Improve security – protect resources and prevent breaches.

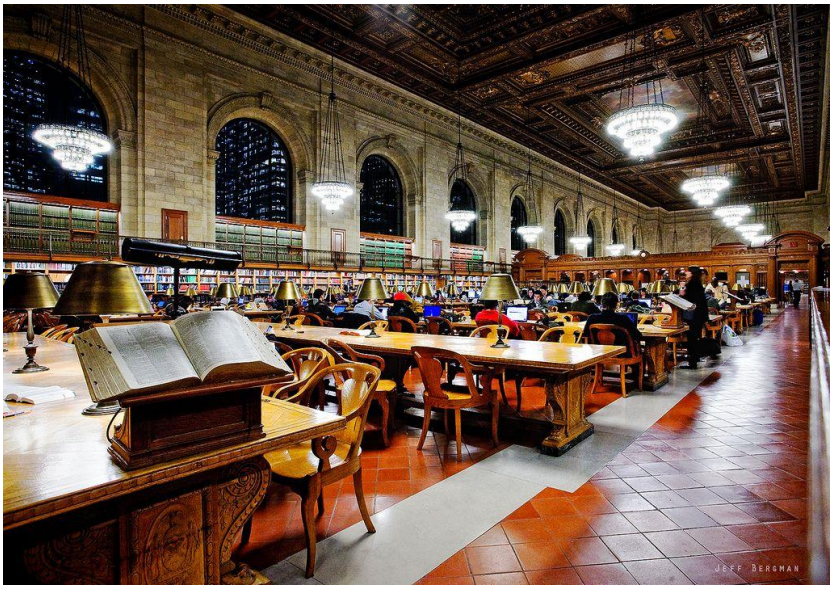
VR and IoT will transform libraries from mere book storage to smart, interactive, and innovative knowledge centers. These technologies will enable libraries to engage and respond to the needs of a new generation of users.

The following services can be offered through integration using the methods listed above .

- **Virtual library tours** — the user walks through the library and views the sections via VR.
- **Educational modules** — interactive lessons, tests, experiments in VR.
- **Cultural heritage exhibits** - viewing historical manuscripts as if you were going to a museum.
- **Electronic catalogs** — recommending relevant literature using AI.
- **User profile** — a personalized library interface based on each user's reading habits.

Some of the proposed methods are being used internationally and achieving the desired results. Let's take a look at some of them .

USA: New York Public Library. This library is considered one of the most modern libraries. The library has organized 3D historical tours, which have significantly increased user visits. Thousands of tourists visit the library every year. The library doesn't stop there, it also has an AI-based recommendation system. Interesting Facts About This Library: It was featured in "Ghostbusters" (1984) and many other movies; it receives over 18 million visitors annually; it offers free access to millions of books and magazines through its electronic library, and hundreds of thousands of virtual visits per day. If you want to visit this library , you can follow its news and events on its official website — www.nypl.org



United Kingdom: British Library

The British Library is the national library of the United Kingdom and is considered one of the largest and most important libraries in the world. The British Library is also far ahead of other libraries in terms of modernity. The fund contains more than 170 million materials (books, manuscripts, maps, sound recordings, etc.).

Modern technologies and services in the library

1. Digitalization initiatives

The British Library is digitizing some of its oldest and most valuable works and making them publicly available online: Digitized Manuscripts, Sounds Archive .

2. VR and AR projects

The "Turning the Pages" project allows users to "turn the pages" of ancient manuscripts in a virtual environment. Using VR technology, ultra-thin books like Cotton Nero Ax are being presented interactively.

The Cotton Nero Ax is a 14th-century manuscript held by the British Library, which contains two important works: "Sir Gawain and the Green Knight" - the most famous Arthurian novel (heroic tale) of the Middle Ages, and "Pearl" ("Margarita") - a religious and philosophical poem dedicated to the author's lost daughter.

3. Big Data and AI integration

Machine Learning algorithms are used to automatically index, add metadata , and translate texts. DataCite and other services allow researchers to manage and analyze their data sets.

4. Open Access and research resources

BL Labs – an open database and tools for researchers.



South Korea: Seoul National Library

South Korea: The National Library of Korea in Seoul is the country's largest and official national information resource center. It is an institution that actively develops not only traditional library services, but also digital transformation, modern technologies , and international cooperation.

Library information:

- Year of establishment : 1945
- The fund size is more than 13 million publications (as of 2024)
- Digital collection of over 3 million digital documents
- User base over a million online users
- Website www.nl.go.kr

Modern technologies and digital capabilities

1. Digital Library

- The National Digital Library of Korea has been active since 2009. can access online classes, e-books, e-lectures , and virtual exhibitions.

- 800+ digital databases: scientific articles, statistics, newspaper archives.

2. AI and Big Data Analysis and text analysis using artificial intelligence .

- Content recommendations are offered based on user behavior through Big Data.

3. VR/AR technologies

- Some sections of the Seoul National Library have been digitized for virtual tours via VR.

- Historical documents and archival materials are being brought to life using AR, especially for younger users.

4. Mobile applications. Through the library mobile application:

- Reading e-books
- Finding a book on the spot via QR
- Study by connecting to the online library

We will look at the prospects for its implementation in the libraries of our country .

Studying the current situation, the following can be said. Library collections are being digitized, there is a high demand for technology and interest in VR among young people, and the possibility of integration with educational institutions exists and is being used.

Considering these existing opportunities, we can suggest the following actions.



We can create opportunities in libraries to view historical scenes in VR - historical processes such as the years of independence, the era of Amir Temur .

AI-powered lesson modules should be developed and implemented for school and university libraries.

AR books - work has begun on the transition to multimedia materials via QR codes, and it is important to increase their number.

to create an interlibrary VR portal and create an online space connecting the libraries of the republic. If we work as a team , it will be easier to create this system.

Conclusion

The rapid development of modern information technologies, especially the development of Virtual Reality (VR) and Artificial Intelligence (AI) technologies, requires a new approach to the activities of libraries and information resource centers (IRCs). Traditional library services — reading books, searching the catalog, asking a librarian — are no longer able to fully meet the needs of today's users. Now digital transformation, interactivity and a personalized approach are becoming the main priorities. From this point of view, there is an opportunity to radically update library services through the integration of VR and AI technologies. Such an approach: Virtually immerses the user in the library environment using VR; offers him personal books, teaching materials, recommendations and excursions through AI; and presents historical, scientific and cultural information in real time, on a visual-sensory basis through 3D excursions. A virtual librarian working on the basis of artificial intelligence — interacts with the user and helps him quickly find the necessary information. Analyzing user behavior, offering electronic resources on relevant topics, and creating individual learning paths - all of these are modern manifestations of advanced library services.

At the same time, 3D historical excursions can bring the younger generation into an interactive and emotional connection with national values and history. For example, traveling through Registan Square via VR, visiting the Amir Temur Palace, or seeing the scientific heritage of great thinkers in virtual laboratories is a process that not only provides knowledge, but also arouses emotions and amazement. Such an approach significantly increases the quality of the educational process. Another important aspect is that these technologies also create great opportunities for inclusive library services. Users with disabilities can use library services without

barriers through VR and AI technologies, and be on an equal footing with their peers in acquiring knowledge, even if they have limited hearing, vision, or mobility.

Thus, the integration of VR and AI will not only modernize the activities of ARMs, but also deepen the interaction between the user and the library, bringing information services to an advanced level. This is the most effective way to form a modern library that combines science, education, culture and innovation in the context of digital transformation.

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ANALYSIS OF THE TOURISM AND RECREATIONAL POTENTIAL OF THE SUGHD REGION

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Abstract. *This article analyzes the tourism and recreational potential of the Sughd Region for development as a strategic area for regional development. It examines landscape features, tourism and recreational resources, the state of specially protected natural areas, and key challenges hindering the effective development of ecotourism: personnel shortages, insufficient study of mountain and valley zones, and weak infrastructure. It also assesses the prospects for developing regional eco-tourism routes and mechanisms for interaction between local residents, government agencies, and tourism organizations. A SWOT analysis identified key areas for optimizing regional tourism policy.*

Keywords: *tourism and recreational potential, Sughd Region, recreational resources, specially protected natural areas, sustainable development, tourism infrastructure, development of tourism potential*

Introduction. Given the limited land resources in mountainous regions, the issue of their rational use is becoming increasingly important. While in densely populated plains every piece of land has high economic value, in sparsely populated mountainous areas there is often inefficient use of resources. One of the most effective and promising solutions to this problem is the development of tourism. The development of tourism in the Republic of Tajikistan depends on the scientifically sound territorial organization of types and forms of tourism in different regions. To ensure the sustainable development of tourism and prevent the exacerbation of socio-economic contradictions that arise in this process, it is necessary to establish regulations for the use of tourist areas, primarily specially protected natural sites. [10.c. 54-56].

Research methods. This study aims to analyze the tourism and recreational potential of the Sughd region, identify key problems and constraints, and formulate practical recommendations for the development of sustainable forms of tourism, taking into account the natural, socio-economic, and cultural characteristics of the region. SWOT analysis was used to provide a more in-depth interpretation of tourism development in the Sughd region. It allowed us to identify the region's strengths and weaknesses, as well as to determine the main opportunities and threats. In addition, an analysis of the political, economic, social, and technological context of innovation policy was conducted. The use of SWOT analysis contributes to a comprehensive assessment of the factors influencing the sustainable development of tourism and the formation of an effective regional strategy.

Research results. Given the relevance of ecological tourism, the goal was set to study the natural resource potential and infrastructure capabilities of the Sughd region. The nature of the Sughd region is extremely diverse, full of striking contrasts and unique landscapes. The specific

nature of the natural components of the Sughd region is of great importance for the development of tourism and non-manufacturing industries. The Sughd region is located in the north of the republic. Individual territories of the Sughd region differ greatly from each other in terms of geographical location, relief features, climate, and combination of altitude zones. In this respect, the nature of the Sughd region has its own characteristics. The mountainous nature of the relief is less pronounced here than in other regions of the republic. Most of the territory is occupied by the plains of the Fergana Valley of the Hungry Steppe. Only to the north and south of them do ridges and mountains rise [2.c.128].

There are prerequisites for the development of recreational tourism in the Sughd region, and this region is one of the most attractive tourist areas in the republic. Based on existing tourist resources, conditions have been created for the development of historical and educational, mountain sports, ecological, medical and health, sanatorium and resort, amateur, and other types of tourism for both domestic and foreign tourists. Table 1.1 presents systematic statistical data reflecting the current state and level of development of the tourism infrastructure in the Sughd region based on the results of the reporting period for 2025. The indicators presented allow for a comprehensive assessment of the level of development of tourism activities, the dynamics of tourist flows, the state of recreation areas, and the availability of infrastructure in the region.

These data are of scientific and practical importance, as they demonstrate trends in the spatial distribution of tourism resources, determine the level of attractiveness of domestic and international tourism, and identify imbalances and possible directions for the further development of the tourism and recreation complex of the Sughd region.

Table 1. Analysis of tourism development indicators in the Sughd region for the first nine months of 2025

№	Indicators	Unit of measuremen	January–September 2025			January–September 202			Compared to last ye	
			Total	Foreign	Internal	Total	Foreign	Internal	Quantitative rati	Percentage ratio
1	Number of tourism companies operating in the cit and surrounding areas	number	42	0	0	45	0	0	-3	93,3
2	Number of domestic and foreign tourists staying i hotels and resorts in the city (and surrounding area	people	116611	25514	91097	10119	20267	8092	15420	115,2
	Number of foreign visitors entering through borde crossings for various purposes	Thousand people	1017,6			790.9			226,7	128,7
3	Number of tourist routes/historical and tourist site		210	-	210	225		225	-15	93,3
4	Types of tourism used by foreign and domestic tourists, including:									
	- - mountaineering	person	264	264	0	28	28	0	236	943
	- - vacation, recreation, and entertainment	person	11587			7672			3915	151,0
	- - retraining and professional developmer	person	1958			959			999	204,2
	- - health rehabilitation and medical	person	33788			36533			-2745	92,5
	- - pilgrimage to holy places	person	472			2334			-1862	20,2
	- - ecological	person	11571			12851			-1280	90,0
	- - related to work and professional activiti	person	28506			22506			6000	126,7
	- - -other types of tourism	person	28729			18336			10393	156,7
5	The availability of facilities and infrastructure tha will facilitate the reception of guests									
	-hotels and other tourist destinations (hostels, touri camps)	places to stay	7441			7324			117	101,6
6	Restaurants and public catering establishments	places for visito								
	-other service outlets									
7	The volume of paid services in all sectors	million somor	4360,0			3689,0			671.0	112,7
	including the volume of hotel and restaurant servic	million somor	655,9			582,4			73.5	107,4

Source: Statistical data from the Tourism Committee under the Government of the Republic of Tajikistan for the first nine months of 2025.

Analysis of the data presented in the table above allows us to draw general scientific conclusions about the current state, dynamics, and prospects for the development of tourism and recreational activities in the Sughd region. The indicators presented testify to qualitative changes in the formation of the regional tourism system, which are characterized by an increase in tourist flows, expansion of infrastructure, and gradual strengthening of the region's integration into the national and international tourism space. An analysis of the table shows that the number of tourism companies operating in the Sughd region in the reporting period is 7 percent less than in the same period last year. The decrease in the number of tourism companies has led to a decrease in the number of tourist routes by approximately 7 percent, which is an alarming indicator. On the one hand, these indicators represent a negative growth rate for the industry, but on the other hand, they show that under the current conditions, this market is free and there are opportunities for the creation of tourism companies.

Based on the types of tourism that foreign and domestic tourists engage in within the region, it can be concluded that tourists are more interested in areas such as working holidays, entertainment, retraining, and professional training, i.e., the growth in these areas during the period under review compared to the same period in 2024 ranged from 150 to 200 percent. However, the main problem is that these types of tourism are only attractive to domestic tourists. Among all the above-mentioned areas, foreigners are more interested in mountaineering, which has increased ninefold compared to last year. Since the subject of our research in this article is the recreational opportunities of the Sughd region, the analysis must take into account the possibilities for the development of ecological tourism. Statistical data show that the state of development in this area is negative and has declined by 10 percent. We believe that the main problems in this case are weak scientific and methodological developments, as well as insufficient accessibility of information about ecotourism sites for tourists.

Thus, it can be concluded that the industry can be made attractive by implementing a number of measures, such as the proper promotion of tourism, the use of institutional opportunities, the attraction and effective use of investments allocated to the industry, and the improvement of the professional skills of industry specialists. One of the most important tasks for the development of tourism in the region is the implementation of investment projects. It should be noted that with the financial support of the Asian Development Bank, Kios Consulting has prepared a list of 25 projects for the development of tourism infrastructure in the Sughd region as part of the development of the “Comprehensive Master Plan for Tourism Development in the Sughd Region”. Four of these projects (two sectoral and two multi-sectoral) have been identified as priority investment projects. Specifically, these are:

• The Fon Mountains Nature and Wildlife Protection Network (sectoral project),

• National Center for Water Sports and Recreation on the shore of the Kairukum Reservoir (sectoral project),

- Khujand Tourism Development Program (multi-sectoral program),
- Ayni Tourism Development Program (multi-sectoral program).

As we have already noted, there are currently 42 tourism companies and two public organizations operating in the Sughd region: the Tourism Development Council and the Zarafshan Tourism Development Association. There are 210 tourist routes in the region, covering all historical and cultural attractions. At the same time, two newly established companies have applied to the Committee for a tourist license, while other companies have applied to expand their

activities. To serve domestic and foreign tourists in the region, there is 1 international airport in Khujand, 6 international border crossing points, and 97 tourist facilities, including:

- 65 hotels,
- 19 sanatoriums,
- 4 camps,
- 4 resorts,
- 2 holiday homes,
- 1 medical center,
- 1 recreation center,
- 1 tourist base with a total capacity of 7,441 beds.

There are 24 museums and 97 shrines in the cities and districts of Khujand, Isfara, Panjakent, Istaravashan, Konibodom, Bobojon Gafurov, Jabbor Rasulov, Asht, Devashchich, Spitamen, Shakhriston, Ayni, and Maschokh [11]. The development of tourism in the region is facilitated by historical sites such as Sarazm, which is more than 5,500 years old, ancient Penjikent, the birthplace of the founder of Tajik-Persian classical literature Abu Abdullokh Rudaki - the village of Panjrud, the Fon and Archamidon mountains, the fabulously beautiful lakes of Kulikalon, Haftkul, Iskanderkul, and others [9.pp.50-54]. According to statistics, in January–September 2025 alone, 1,017,600 visitors from the Commonwealth of Independent States and foreign countries entered the Sughd region through border crossings for various purposes, which is 226,700 more than in the same period last year, or 128.6% .

In particular, entry was granted for the following purposes: [11.]

- 289 people — diplomatic purposes,
- 282 people — official purposes,
- 5,121 people — business purposes,
- 5,004 people — work purposes,
- 46,514 people — tourism purposes,
- 2,605 people — educational purposes,
- 7,600 people — personal purposes,
- 39,985 people — trips,
- 26,092 people — transit, etc.

Guests came mainly from the following countries: Greece (389), Denmark (240), Lithuania (225), Germany (2,996), Poland (2,251), India (413), Azerbaijan (335), Switzerland (565), Kazakhstan (16,262), Uzbekistan (610,130), Taiwan (383), Kyrgyzstan (89,944), Turkmenistan (709), New Zealand (389), Korea (975), Czech Republic (491), China (7,159), Japan (2,368), Belgium (442), Georgia (137), Italy (2,323), Canada (657), Latvia (178), Turkey (1,069), Austria (314), Belarus (727), Hungary (217), Spain (711), Mexico (53), Moldova (879), Romania (245), Thailand (162), Ukraine (1,030), France (1,744), Sweden (354), Estonia (124), Brazil (231), Ireland (170), Malaysia (552), Norway (269), Pakistan (463), Singapore (540), Slovakia (205), Philippines (484), Australia (1,859), Bangladesh (250), Indonesia (527), Netherlands (1,019), Russia (256,096), United Kingdom (942), United States (3,704), Iran (717), etc.

During this period, 116,600 people stayed and received treatment in hotels, sanatoriums, and resorts in the region, which is 115.2% more than during the same period last year. Of these, 91,000 were citizens of the Republic of Tajikistan, and 25,500 were foreign visitors. According to preliminary data, during the same period, more than 190,700 people, including about 27,000

foreign tourists and 163,800 citizens of the country, visited historical and cultural attractions, parks, and boulevards in the region.

Advantages

Key improvements:

1. Broke long sentences into logical blocks for better readability.

2. Standardized the formatting of numbers and units of measurement (e.g., “thousands of people,” “%”).

3. Lists of goals and countries are formatted as bullet points for clarity.

4. A formal and scientific style was used, appropriate for statistical and analytical reports.

In the Sughd region, given the abundance of natural, historical, and cultural resources, tourism is considered one of the priority areas of the region's economy. Analyses show that every year, a large number of tourists engage in such types of tourism as historical and cultural, ecological, mountain, health resort, and resort tourism. Social and cultural sites, including immovable material and historical and cultural values, play an important role in satisfying the spiritual needs of tourists and improving their health. Tajikistan, being a mountainous country, has rich ecological and tourist resources for organizing various types of tourism: ecological agricultural tourism, scientific and adventure tourism, sanatorium and resort treatment (Gissaro-Rasht zone, western part of the Fergana zone, and mountainous Badakhshan), ethnic and sports tourism, etc.

Ecotourism, as a specific form of tourist and recreational activity, combines recreation with minimal impact on natural ecosystems. Its goal is to study spatial patterns and the functioning of resources for the development of ecological types of tourist facilities. At present, the potential of ecological types of tourist facilities in the tourist and recreational areas of the republic has not been sufficiently studied. [2.c.54-56]. The lack of professionally trained specialists – geographers, biologists, geologists, guides, and tour guides with experience working in the mountainous and high-altitude conditions of the republic – is an obstacle to the successful development of ecotourism. As the material production sectors grow and the territory for their development expands, ecological tourism, especially in the Gissar Valley, must develop sustainably.

The combination of natural and geo-ecological features of the Sughd region, including the western part of the Fergana Valley with plains at the foot of the mountains and slopes of the ridges near it, as well as the Zeravshan Valley, surrounded by the Fergana Mountains in the northeast and the Kuram Mountains in the northwest. The Shahin recreation and health center for children, teenagers, and young adults in Guliston, the recreation and health center for children, teenagers, and young adults named after the 20th anniversary of Tajikistan's independence, located in the Jabbor Rasulov district, “Avissiti” in the city of Istaravshan, the “Khujand Grand Hotel” and “Khujand Deluxe” hotels in the city of Khujand, Nuri Rahmon in the Aininsky district, Sipekhr and Shohkant in the city of Boston, the Sogd entertainment center, the fountain complex, the statue of King Ismail Somoni, the Istiklal historical and cultural complex in the city of Khujand, etc. According to experts, the presence of this infrastructure is one of the key factors in the development of ecotourism in the Sughd region and plays an important role in increasing the income of the population and the overall development of the region's economy.

Despite its vast resources, many of the tourist and recreational areas of the mountainous and valley landscape of the Sughd region, including hundreds of unexplored corners of nature, remain poorly studied. For example, in the Zarafshan, Iskandar Kul, and the Yagnob National Nature Park, there are many tourist destinations, such as geomorphological, litho-paleontological,

tectonic, hydrological, and petrographic-mineralogical sites, which have not yet been sufficiently explored for the development of ecological tourism [10.c.4]. Due to the lack of research into the mountain and valley conditions of the Sughd region, travel to the hundreds of untouched corners of nature is not considered possible. Resources for the sustainable development of ecotourism are extensive in almost all tourist and recreational areas of the republic.

Of particular interest is the western part of the Fergana recreational zone, where there are unique ecological resources associated with such sites as the “Tajik Sea,” “Koni Mansur,” the underground labyrinths of Karamazara, dinosaur tracks and stone trees of Ravota, as well as Black Ore and Aksukona [3. c.156]. The space for ecological tourism and the location of ecotourism and recreational services in the Sughd region are organized by beautiful and unique nature in specially protected natural areas (SPNA), such as five nature reserves and one national park (Table 1), with a total area of 107,690 hectares, which make a significant contribution to the protection of flora, fauna, and natural landscapes [5.p.88].

Table 2. System of protected areas of the Sughd region

№	**Name of protected area**	**Day, month, and year of establishment**	**Area. ha**	**Administrative-territorial division**	**Purpose of the nature reserve**
1	Makon Sugur Nature Reserve (Oktosh)	30.12.1977	15049	Ashta District	Protection and restoration of the Menzbir marmot species, listed in the Red Book
2	Dara Sabz Nature Reserve (Kusavlisoy)	09.05.1959	18266,99	Shakhriston District	Protection and restoration of juniper groves and preservation of unique flora and fauna
3	Orion Nature Reserve (Soyvota)	01.03.1972	4120	Aynin District	Protection and restoration of juniper groves on the slopes of the Zarafshan Range
4	Zarafshan Nature Reserve	10.06.1976	2380	Penjikent City	breeding and protection of the rarest natural population of a pheasant subspecies
5	Iskandar Kul Nature Reserve	12.12.1969	27874	Aynin District	protection of wonderful and beautiful places, juniper forests, mountain goats, and the unique nature of this valley in general
6	Yagnob National Nature Park	02.05.2019	40000	Aynin District	preservation of the unique gene pool of fauna and flora, ecosystems, natural and historical resources

Compiled by the authors based on scientific works [3.p.153, 4.p.58, 5.p.94].

The deterioration of the ecological situation and the increase in man-made pollution require a careful approach to nature. Eco-tourism is the only branch of the recreation industry that seeks to preserve natural landscapes considered to be national treasures. This study aims to address issues related to the development and improvement of the network of protected areas in the Sughd region and throughout the country as a whole by developing eco-tourism and promoting this type of environmental activity. The nature of this area is of unparalleled beauty, adorned with giant stone flowers—snow-white vases formed by salt deposits from underground mineral springs. When organizing ecotourism, tourist agencies should pay special attention to the rational use of resources and their tourist and recreational value, in particular: land plots, water resources, natural complexes and objects of special environmental, scientific, cultural, aesthetic, recreational, and health significance [10.p. 38].

Traveling to unspoiled landscapes to explore their ecological, cultural, and ethnographic riches is hugely popular around the world. Tajikistan has not been left behind by this rapidly developing trend in recent years. The growth of ecotourism in the country is largely due to its extensive network of specially protected natural areas (SPNAs). These include wildlife sanctuaries, nature reserves, and national parks, all of which offer eco-routes for tourists seeking an exciting encounter with wildlife.

It should be borne in mind that in the territorial organisation of tourism and recreational activities, the tasks of specially protected areas are primarily determined by the protection of these ecosystems, the preservation of exotic natural and cultural objects to meet the recreational needs of ecotourists, the conduct of scientific research, and fostering in visitors a love for nature and the natural resources of Tajikistan and a careful attitude towards them. Within each of these areas, it is necessary to designate: a reserve area, a buffer zone, and a recreational area. Such types of territorial organization have not yet been established in the specially protected reserve areas of the republic [9.p.54].

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2. Preservation of the appearance of 47 geolandscapes and protected natural and historical areas: this involves ensuring careful treatment of nature and preserving its uniqueness for future generations. Introduce strict rules of conduct in protected areas, organize a control and monitoring system, and develop environmentally sustainable tourism. It is necessary to invest in infrastructure

that minimizes the impact of tourism on the environment and to develop the principles of sustainable development.

3. Based on the fact that it is the citizens who are the creators of all the elements of life, customs, historical and cultural heritage, folklore, and folk crafts of individual destinations in the republic (Gissar, Vakhsh, Kulob, Rasht, Western and Eastern Pamir), shape the public opinion of local residents on strengthening responsibility for the protection of the above-mentioned elements.

The development of ecological, mountain, cultural, and medical tourism, as well as the strengthening of cultural ties through tourism, can transform the Sughd region into an attractive world-class destination and improve the living standards of the local population. Therefore, tourism, as an important driver of the economy and a factor of social progress, occupies a special place in state policy. Thus, by conducting a SWOT analysis, it is possible to identify the strengths and weaknesses, as well as the opportunities and existing threats in the region's tourism sector (Fig. 1).



Fig. 1. SWOT analysis of the tourism industry in the Sughd region

In conclusion, it should be noted that the Sughd region is one of the most promising tourist regions of the Republic of Tajikistan, with significant natural, historical, ethnographic, cultural, and recreational potential. The region's tourist appeal is shaped by a variety of resources, including snow-covered ski slopes, hunting and fishing opportunities, specially protected natural areas, historical, cultural, and architectural heritage sites, as well as industrial and geological tourist attractions.

Favorable natural and climatic conditions and a rich cultural heritage create the conditions for the organization and development of various types of tourism and recreation. Priority areas include health and recreational tourism, hiking and mountaineering, ecotourism (including ecological routes in specially protected natural areas), ethnotourism, and sports tourism. In addition, in 2025, the region hosted significant cultural events and the international forum "Sogdiana Region – Crossroads of the Great Silk Road. Journey to the Heart of Eurasia – 2025," which contributed to raising the region's tourist profile at the national and international levels. Studying successful practices and implementing innovative approaches will unlock the full potential of ecotourism for the benefit of local communities and the entire planet, contributing to a more sustainable and equitable future for all. Therefore, in order to further increase tourist attraction, it is necessary to develop and improve the national tourism industry, especially in terms of creating tourist infrastructure in accordance with modern requirements and tourist needs.

Thus, achieving sustainable tourism development, which is the goal of the country's current tourism policy, provides an opportunity:

Firstly, it contributes to the introduction of resource-saving technologies and the modernisation of production, which is a necessary condition for improving environmental efficiency and preventing natural and man-made emergencies, especially in the mountainous areas of the republic.

Secondly, it allows for maximising revenue from the use of natural and tourism resources, which goes to the republican and local budgets, which in turn allows for the rational use of tourist and recreational areas.

Thirdly, advertising is one of the most important and integral parts of the tourism industry, one of the main means of marketing communication. It is implemented not only for foreign tourists, but also for domestic tourists, so that every Tajik citizen or guest of the country can enjoy the unique nature of 'Dara Sabz' and visit it.

Fourthly, it is necessary to strengthen cooperation between the population and local authorities. Residents of tourist areas should be persuaded to provide adequate tourist services in order to generate significant income, which will help to solve everyday problems, improve their social situation and provide jobs.

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DIRECTIONS FOR IMPLEMENTING COMMUNICATION MANAGEMENT AT INVESTMENT FORUMS

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Abstract. *The article analyzes the issue of institutionalizing practical experience in interaction between the state and both local and foreign mass media in the localization of interaction practices at international investment forums. It is suggested that, in practice, the support provided by the media to such events is largely uneven and collective in nature, manifesting as a series of fragmented information actions that are not combined into a unified chain of managerial logic and are not part of the logic of the state investment cycle. Based on the analysis of the media plan and a number of organizational measures adopted for the study of an international investment forum, the necessity of transitioning from an event-oriented and reactive model to a traditional communications management model is substantiated, with the aim of establishing investor trust, publicly consolidating agreements, and facilitating investment decision-making. The proposed model encompasses the entire cycle of work with the media—from the creation of media infrastructure and early positioning of the forum to post-event support and the institutionalization of results. This study is scientifically novel in its formalization of media practices as a reproducible managerial mechanism within the system of state investment policy.*

Keywords: *communication management, public administration, mass media, international investment forum, media plan, standard model, investment policy.*

Introduction

In the contemporary period, international investment forums have become an established instrument of state investment policy as well as an important aspect of communication with foreign countries. Nevertheless, informational support for these events now goes beyond the simple recording of the fact of their occurrence - it is tied to events separately and independently in order to shape the perception of the country as an investment destination. Mass communication theory emphasizes that mass media not only record events but also help create the social meaning of their significance by organizing a framework for interpretation and audience attention (McQuail).

For investment processes, this means that media coverage surrounding a forum also becomes part of the investment signal addressed to both external and internal stakeholders. Experience shows that investors view public communication by the state as a marker of institutional capacity, process manageability, and the ability to support projects at all levels - from initial outreach to development.

However, in the activities of public institutions, media support for forums typically remains operational and is not considered an aspect of communication at the level of investment cycle management. As a result, the actual experience of press service staff and event organizers remains informal in a significant number of cases, relying on professional skills and competencies, and does not become a viable managerial model. This limits the reproducibility of effective approaches and the prospects of media communications as an instrument of investment policy.

Empirical Base and Research Methodology

The empirical content of the study was built on the media plan and the plan for organizing media coverage of an international investment forum, as well as on materials from the practical activities of public authorities in organizing cooperation with local and foreign media. This analysis was compiled from documents regulating digital development, the engagement of PR companies, the accreditation of foreign journalists, the creation of a press center, broadcast administration, and the production of media coverage. The available materials did not contain a single approved regulation but were generated within the context of the professional operational functions of specialized actors as they are already implemented in practice. This led the study to formulate a strategy oriented toward analytical generalization of consolidated experience and the transformation of data into a model that can be used as a reproducible and implementable tool in the work of national authorities. From a methodological perspective, the research is based on systemic and process-oriented approaches, as well as on the foundations of communication management theory and institutional communications. The study seeks to identify a stable managerial logic of working with the media and its standardization through a classical model.

Cooperation with the Media in Organizing Communication Management of an Investment Forum

Within the communication management system of an international investment forum, work with mass media should function as a separate managerial loop within the holistic construction of the investment cycle. Media thus serve not only as channels for disseminating information but also as interfaces between managerial practices inside and outside such processes. In this context, according to research on network communications, with the global information environment in the background, state communication increasingly becomes distributed and requires the management of information flows and interpretations at all times (Castells).

For investment stakeholders, this implies the necessity of pre-designing media communications rather than reacting to events on site. Media cooperation at the forum should align with the program of events, negotiations, signing ceremonies, exhibition activities, and similar components. Each forum event should be understood not in isolation but as part of an interconnected communication network designed to build trust and seek ways of public coordination. Consequently, media support for the forum ceases to be a service function and becomes an instrument for the controlled formation of investment expectations.

A Standard Model for Working with Local and Foreign Media

The proposed standard model of interaction with the media envisages three interrelated stages: the preparatory stage (infrastructure creation and preliminary PR), the forum stage (operational management of media flows), and the post-event stage (post-PR and institutionalization of results).

Basic media infrastructure and the first stage of positioning.

At the first stage, basic digital platforms for forum coverage are created (the official forum website, the website of the relevant ministry, and official social media accounts). The resources of these platforms are synchronized in advance in terms of structure, visual style, and terminology. In parallel, a detailed media plan is prepared - for example, which forum events (plenary session, panel and pitch sessions, B2B meetings, signing ceremonies, exhibition) will be covered and in what form. The media plan specifies that news events are released together with extended press releases, and that video segments with interviews are prepared for each of them.

Lists of national and foreign media are compiled according to their specialization and audience. The Ministry of Foreign Affairs organizes the accreditation of foreign journalists. At the

same time, communication platforms for rapid interaction with the media are developed - closed groups via messengers and cloud storage systems, where press releases, key statements, and the results of negotiations for each forum event are updated in real time. One of the key aspects of this stage is advance PR. Foreign journalists notify their target audiences in advance about invitations to participate in the forum, which serves as an additional factor of information dissemination. The preliminary production of promotional videos on the country's investment potential, key sectors, and reforms is carried out in advance and used in digital channels and on forum screens. At present, a professional PR company independently manages the entire media production cycle: it prepares materials for each panel and pitch session, conducts interviews, photo and video shoots, produces daily and final videos, and plans online broadcasts on the ministry's official channels.

Forum Stage: Media Flow Management

Media work at the forum is characterized by continuous operational management. A separate technical unit is established to manage LED screens, conduct live broadcasts from forum sessions, and coordinate visual content with events. The press center also functions as a service platform, offering journalists workspaces, translation services, and immediate access to materials. Each major publication, including photographs and press releases, is published online and produced in a convenient linguistic format, preserving the key characteristics of information transmission in the spirit of the classical communication model "who says what through which channel" (Lasswell).

Interviews with leading forum participants are organized on site - in corridors, halls, during coffee breaks, and between sessions. These interviews are pre-coordinated with the press services of VIP guests and are immediately distributed to the media, displayed on forum LED screens, and published on other digital media resources. Media coffee breaks perform an additional function: they are perceived not merely as a protocol detail or an issue of etiquette, but as a managed window for communication and media invitations. This strategy minimizes chaotic interaction between journalists and speakers and improves media quality.

After the Event: Post-PR and Institutionalization

After the forum, media work transitions to a platform for supporting and consolidating results. Final publications, including concluding press releases, video materials, and analytical documents, are distributed to national and foreign media, ensuring that the event leaves a long-term informational footprint. The work includes offering additional commentary and analytical materials to foreign journalists, taking into account the specifics of national media systems, in line with comparative media studies (Hallin, Mancini).

Conclusion.

Based on the experience gained, the final concept of the model becomes an analytical fixation of media work results and in accordance with accumulated experience, the standard model can be updated. Thus, practical experience does not dissipate but becomes part of the institutional memory of a public authority.

The research results show that structured integration with the media at international investment forums is a matter of institutionalization and a transition from event-based approaches to an integrated management model. By integrating media practices into the communication management of the investment cycle, information processes can be implemented with greater managerial ease, investor trust can be strengthened, and the potential for successful decisions can be assessed.

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CRITICAL DETERMINANTS OF CRISIS MANAGEMENT EFFECTIVENESS IN CONSTRUCTION ENTERPRISES: A COMPREHENSIVE ANALYSIS

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Abstract. *The construction industry operates within the environment characterized by inherent volatility, extended project lifecycles, substantial capital requirements, and significant exposure to external economic fluctuations. These characteristics render construction enterprises particularly vulnerable to crisis situations that can threaten organizational survival and long-term viability. This paper presents a systematic examination of the multifaceted factors that determine crisis management effectiveness in construction enterprises, drawing upon contemporary research and industry practice. Through comprehensive analysis of economic, financial, operational, and organizational dimensions, this study identifies and evaluates the critical determinants that influence a construction firm's capacity to anticipate, respond to, and recover from crisis events. Particular emphasis is placed on examining the interplay between external market forces and internal organizational capabilities, including financial resilience, strategic adaptability, risk governance frameworks, human capital development, and stakeholder relationship management. The research reveals that construction enterprises face unique challenges during crisis periods due to their project-based operational model, dependence on extensive supply chains, exposure to regulatory changes, and reliance on external financing. The findings demonstrate that effective crisis management requires a holistic approach that integrates proactive risk identification, flexible organizational structures, robust financial management, strategic human resource practices, and collaborative partnerships. This paper contributes to the growing body of knowledge on organizational resilience in the construction sector by providing empirically grounded insights into the factors that enable construction enterprises to maintain operational continuity and competitive positioning during turbulent periods. The conclusions offer practical implications for construction management professionals, policymakers, and researchers seeking to enhance crisis preparedness and organizational sustainability in this critical economic sector.*

Keywords: *construction management, crisis management, organizational resilience, risk management, financial sustainability, construction industry.*

Introduction

The construction industry represents a cornerstone of economic development and infrastructure advancement, yet it simultaneously stands as one of the most crisis-prone sectors in the global economy. Research consistently demonstrates that construction enterprises experience more severe impacts from economic downturns compared to firms in many other industries (Ruddock et al., 2014). This heightened vulnerability stems from the industry's distinctive characteristics: high capital intensity, extended project timelines, complex stakeholder networks, and profound dependence on economic cycles and external financing (Hillebrandt, 2000).

Recent global events, including the 2008 financial crisis and the COVID-19 pandemic, have underscored the critical importance of robust crisis management capabilities in the

construction sector. During the 1997 Asian financial crisis, for instance, approximately 97% of contractors in Singapore reported substantial losses, with construction firm cessations rising by 49% within a single year (Lim, Oo and Ling, 2010). Similarly, the COVID-19 pandemic exposed fundamental vulnerabilities in construction supply chains, workforce management, and project delivery systems, compelling organizations to rapidly adapt their operational models (Brudenell, 2020).

The concept of crisis management in construction has evolved considerably from reactive problem-solving to encompass proactive preparedness, adaptive capacity building, and strategic resilience development (Hällgren and Wilson, 2008). Contemporary scholarship recognizes that effective crisis management extends beyond immediate response mechanisms to include systematic risk anticipation, organizational flexibility, and the cultivation of capabilities that enable firms to not merely survive crises but potentially emerge stronger from disruptive events (Chih et al., 2022).

Despite growing recognition of crisis management's importance, many construction enterprises continue to exhibit inadequate preparedness. Research indicates that corporate philosophies in construction companies often fail to adequately support crisis management activities, with planning frequently remaining rudimentary, insular, and poorly resourced (Loosemore, 1998). This deficiency creates significant vulnerabilities, as construction firms may lack comprehensive understanding of their crisis exposure, appropriate response mechanisms, and recovery strategies.

This paper addresses this critical gap by systematically analyzing the key factors that influence crisis management effectiveness in construction enterprises. The analysis encompasses multiple dimensions—economic environmental factors, financial capacity determinants, market dynamics, risk governance frameworks, human capital considerations, partnership networks, and institutional contexts—recognizing that these elements interact dynamically to shape organizational resilience. Understanding these factors and their interdependencies is essential for developing integrated crisis management strategies that can enhance both immediate survival capabilities and long-term competitive sustainability.

2. The Economic Environment: External Forces Shaping Crisis Vulnerability

The economic environment is a primary external driver of crisis vulnerability in construction enterprises. Construction activity is highly cyclical and more volatile than the broader economy due to the derived nature of its demand (United Nations, 1976; Nam and Tatum, 1988).

2.1 Economic Cycles and Construction Demand Dynamics

Construction demand closely follows economic cycles but with greater intensity and faster adjustment (Riggleman, 1933). Economic expansions stimulate growth through increased investment and public spending, whereas recessions disproportionately reduce construction activity as capital expenditures decline (Dang and Low, 2015). Structural characteristics—such as immobile outputs, high capital intensity, and limited capacity flexibility—prevent inventory buffering and amplify boom–bust dynamics (United Nations, 1976). Market cycle studies further indicate that growth phases strain labor and margins, static phases limit investment incentives, and downturns force cost reductions and strain financial relationships (Baker Tilly, 2020).

2.2 Interest Rates and Financing Accessibility

Interest rate movements exert profound influence on construction activity through multiple channels. Rising interest rates increase borrowing costs for construction enterprises, making it more expensive to finance projects, purchase equipment, and manage working capital

requirements (Bernanke, 2010). Simultaneously, higher rates reduce demand for construction outputs by diminishing affordability for end-users, particularly in interest-sensitive segments such as residential and commercial real estate (Allianz Trade, 2024). The 2008 financial crisis vividly illustrated the devastating impact of credit market disruptions on construction enterprises. Tightened lending standards and reduced credit availability left many construction firms unable to secure the financing necessary for operational continuity, contributing to widespread business failures (Nistorescu and Ploscaru, 2010). Even well-capitalized firms with strong operational performance found themselves vulnerable when credit markets seized, highlighting the critical importance of diverse financing sources and robust banking relationships.

2.3 Material Cost Volatility and Supply Chain Disruptions

Construction enterprises face continuous exposure to fluctuations in material costs, which can dramatically affect project profitability and financial stability. Unlike many industries where input costs remain relatively stable, construction material prices exhibit substantial volatility driven by commodity market dynamics, supply-demand imbalances, transportation costs, and global trade patterns (Ross, 2024). The COVID-19 pandemic exemplified this vulnerability, as supply chain disruptions and surging demand created unprecedented price inflation for essential materials including lumber, steel, and cement. Material cost volatility poses particular challenges for construction firms operating under fixed-price contracts, where the risk of cost overruns falls entirely on the contractor. Even with price escalation clauses, significant material cost increases can erode project profitability and strain cash flow. Construction enterprises must therefore develop sophisticated procurement strategies, maintain diverse supplier networks, and implement effective hedging mechanisms to manage material cost risks (Allianz Trade, 2024).

2.4 Public Sector Investment and Countercyclical Policies

Government construction spending plays a crucial role in moderating cyclical fluctuations in the construction industry. During economic downturns, governments frequently implement countercyclical infrastructure investment programs to stimulate employment and economic activity (Gruneberg, 1997; Hillebrandt, 2000). These initiatives provide critical demand stabilization for construction enterprises when private sector activity declines, offering opportunities for firms to maintain operational capacity and workforce retention during recessionary periods. However, reliance on public sector work introduces its own vulnerabilities. Government projects often involve complex procurement processes, extended approval timelines, and exposure to political changes that can result in project cancellations or funding reductions. Construction enterprises must therefore carefully balance their portfolios between public and private sector work, recognizing the different risk profiles and revenue characteristics of each segment.

3. Financial Capacity: The Foundation of Crisis Resilience

Financial capacity represents perhaps the most critical internal factor determining a construction enterprise's ability to withstand and recover from crisis situations. The construction industry's project-based business model, with its irregular cash flows, substantial working capital requirements, and exposure to payment delays, creates unique financial management challenges that become particularly acute during crises.

3.1 Liquidity Management and Working Capital

Liquidity—the ability to meet short-term financial obligations—is central to the survival of construction enterprises, especially during crises marked by revenue uncertainty and tighter credit conditions. Research identifies inadequate liquidity as a leading cause of construction firm

failure, even among companies with profitable operations and strong order books (Nistorescu and Ploscaru, 2010). Because construction projects require substantial upfront capital before client payments are received, firms often face negative cash flows that heighten vulnerability to payment delays and economic shocks. Effective liquidity management therefore depends on sufficient cash reserves, access to reliable credit facilities, disciplined receivables collection, and careful timing of payables (Kovalev and Kovalev, 2024). Evidence from the 2008 financial crisis further illustrates that firms with conservative cash positions and diversified funding sources were better able to meet immediate obligations and withstand financial stress.

3.2 Debt Management and Capital Structure

The structure and level of a construction enterprise's debt significantly influence its crisis vulnerability and response flexibility. While leverage can enhance returns during favorable periods, excessive debt creates fixed obligations that become burdensome when revenue declines. Research examining construction firms during the 2008 financial crisis found that highly leveraged companies faced greater financial distress and higher failure rates compared to firms with more conservative capital structures (Nistorescu and Ploscaru, 2010).

3.3 Cost Control and Financial Discipline

During crisis periods, the ability to rapidly adjust cost structures becomes essential for organizational survival. However, indiscriminate cost cutting can prove counterproductive if it damages essential capabilities, employee morale, or client relationships. Research on SME resilience during financial crises emphasizes that effective financial management—encompassing cash flow management, debt restructuring, and diversified funding sources—represents a crucial determinant of survival and recovery (Preprints.org, 2024). Construction enterprises must develop sophisticated financial planning and monitoring systems that provide early warning of emerging problems while enabling rapid response when necessary.

4. Market Positioning and Adaptive Capacity

The ability to adapt to changing market conditions represents a critical determinant of crisis management effectiveness in construction enterprises. Market demand volatility, shifting customer preferences, and competitive dynamics create continuous pressure for strategic repositioning and operational flexibility.

4.1 Portfolio Diversification and Market Agility

Construction enterprises with diverse portfolios across project types, geographic markets, and client segments typically demonstrate greater resilience during crises compared to firms concentrated in narrow niches. When economic downturns reduce demand in specific sectors—such as commercial office construction following the shift to remote work—firms with diversified capabilities can redirect resources toward more stable segments (Ross, 2024). However, diversification strategies must be carefully calibrated. Excessive diversification can dilute organizational focus, spread management attention too thin, and reduce competitive advantages in core markets.

4.2 Service Innovation and Value Differentiation

During crisis periods, price-based competition typically intensifies as construction firms compete aggressively for reduced volumes of available work. This dynamic can drive margins to unsustainable levels, threatening the viability of all market participants. Construction enterprises that can differentiate their offerings through superior quality, innovative delivery methods, specialized capabilities, or enhanced services are better positioned to maintain acceptable margins rather than competing solely on price (Low et al., 2009). Building Information Modeling (BIM),

sustainable building practices, modular construction techniques, and integrated project delivery approaches represent examples of innovations that can provide competitive differentiation (Elghaish et al., 2021). However, implementing such innovations requires sustained investment in technology, training, and process development—investments that may seem discretionary during crisis periods but can provide crucial competitive advantages for firms that maintain their commitment to advancement.

4.3 Customer Relationship Management

Strong client relationships provide construction enterprises with several advantages during crises: preferential access to available projects, greater likelihood of contract modifications to address changing circumstances, reduced competitive pressure on pricing, and faster payment processing. Construction firms that have invested in building trust-based relationships with key clients are better positioned to maintain business continuity during downturns (Jayalath, 2023). Effective customer relationship management extends beyond project execution to encompass proactive communication, transparency about challenges and solutions, flexibility in addressing client concerns, and demonstrated commitment to long-term partnerships rather than transactional interactions.

5. Risk Governance and Management Systems

The inherently risky nature of construction activities makes effective risk governance a fundamental component of crisis management capability. Construction projects face multiple categories of risks—safety hazards, cost overruns, schedule delays, quality deficiencies, contractual disputes, environmental liabilities, and regulatory compliance challenges—any of which can escalate into organizational crises if inadequately managed (Hinsberg and Lamanna, 2024).

5.1 Systematic Risk Identification and Assessment

Effective risk governance begins with systematic processes for identifying and evaluating potential risks before they materialize into crises. Research on construction risk management emphasizes the importance of structured risk identification methodologies including brainstorming workshops, historical analysis, root cause analysis, and expert consultations (Texas A&M University, 2025). These processes should occur not only during initial project planning but continuously throughout project lifecycles as conditions evolve and new risks emerge. Risk assessment involves evaluating both the probability of risk occurrence and the potential magnitude of impact if risks materialize. Construction enterprises should develop comprehensive risk registers that document identified risks, assign ownership responsibility, establish monitoring indicators, and define response strategies (ProjectManager, 2025). However, research indicates that many construction companies continue to approach risk management in informal, fragmented ways that leave them inadequately prepared for crisis events (Loosemore, 1998).

5.2 Risk Mitigation and Transfer Strategies

Once risks are identified and assessed, construction enterprises must determine appropriate response strategies. Four fundamental approaches exist: risk avoidance (declining to pursue high-risk opportunities), risk mitigation (implementing measures to reduce probability or impact), risk transfer (shifting risk to other parties through contractual arrangements or insurance), and risk acceptance (consciously retaining risks with appropriate contingency planning) (BigRentz, 2024). Contracts serve as primary mechanisms for risk allocation among project participants in construction. Well-structured contracts clearly define responsibilities, establish procedures for addressing changed conditions, provide mechanisms for dispute resolution, and create balanced

risk distribution that incentivizes all parties to perform effectively (FMI Corporation, 2016). Poorly drafted contracts, conversely, can concentrate risks inappropriately, create ambiguities that lead to disputes, and establish terms that prove financially unsustainable when market conditions change. Construction enterprises must develop deep understanding of contract risk implications and negotiate provisions that create reasonable risk allocation rather than accepting unfavorable terms in pursuit of immediate revenue. This requires sophisticated contract management capabilities, including legal expertise, insurance knowledge, and understanding of market risk dynamics (International Risk Management Institute, cited in Texas A&M University, 2025).

6. Human Capital and Organizational Culture

Human capital, especially effective leadership and workforce adaptability, is the key driver of organizational resilience during crises.

6.1 Leadership Capabilities and Crisis Decision-Making

Effective crisis management requires leadership capabilities that may differ substantially from those needed during stable periods. Crisis situations demand rapid decision-making under conditions of high uncertainty, clear communication to diverse stakeholders, ability to maintain team cohesion under stress, willingness to make difficult choices including resource reallocation and restructuring, and capacity to inspire confidence despite challenging circumstances (Douglas, 2021). Research on organizational resilience emphasizes that leadership effectiveness during crises depends not only on technical competence but also on emotional intelligence, stress management capabilities, and authentic communication (Preprints.org, 2024). Leaders who can acknowledge difficulties while conveying realistic optimism and clear direction help organizations navigate crises more effectively than those who either deny problems or communicate excessive pessimism.

6.2 Workforce Flexibility and Adaptability

The project-based nature of construction creates inherent workforce flexibility through the use of temporary employees and subcontractors. While this flexibility can facilitate rapid downsizing during crises, it also creates challenges related to skill retention, organizational knowledge preservation, and capacity restoration when conditions improve (Lengnick-Hall et al., 2011). Construction enterprises that entirely eliminate staff during downturns often struggle to rebuild capabilities when recovery begins, facing costs and delays associated with recruiting and training new personnel. Effective human capital strategies during crises balance the need for cost reduction against the importance of preserving core capabilities and institutional knowledge. This may involve implementing temporary salary reductions, reduced work schedules, or assignment flexibility rather than wholesale terminations (Branicki et al., 2018). Such approaches can maintain workforce capability while controlling costs, positioning firms for more rapid recovery when market conditions improve.

6.3 Training and Development Investment

During crisis periods, training and development programs often face pressure for elimination as seemingly discretionary expenses. However, research suggests that continued investment in human capital development during difficult times can provide significant advantages. Organizations that maintain training commitments signal confidence in long-term viability, strengthen employee loyalty and engagement, develop capabilities that will prove valuable during recovery, and sustain productivity through skill enhancement (Sutcliffe and Vogus, 2003). Strategic human resource management practices that emphasize capability building, continuous learning, and employee resilience contribute significantly to organizational

resilience during crises (Lengnick-Hall et al., 2011). Construction enterprises should view human capital investment not merely as a cost to be controlled but as a strategic asset that enables adaptive capacity and competitive differentiation.

6.4 Organizational Culture and Psychological Resilience

The psychological and cultural dimensions of organizations significantly influence crisis response effectiveness. Research identifies that organizational cultures characterized by trust, open communication, collective problem-solving, and shared commitment to organizational success enable more effective crisis management than cultures marked by hierarchy, blame, and political maneuvering (Chih et al., 2022). During the COVID-19 pandemic, construction enterprises with strong organizational cultures demonstrated greater resilience through enhanced cooperation, creative problem-solving, mutual support among employees, and maintenance of productivity despite challenging conditions (Brudenell, 2020). Building such cultures requires sustained leadership attention and cannot be created quickly when crises emerge. Construction enterprises should therefore view culture development as a long-term investment in crisis preparedness and organizational resilience.

7. Partnership Networks and Collaborative Relationships

Construction enterprises operate within extensive networks of relationships with subcontractors, suppliers, professional service providers, financial institutions, and industry associations.

7.1 Supplier and Subcontractor Relationships

Strong relationships with reliable suppliers and subcontractors provide construction enterprises with several crisis management advantages: prioritized access to materials during shortages, greater flexibility regarding payment terms during cash flow challenges, collaborative problem-solving when project challenges emerge, and shared commitment to project success rather than opportunistic behavior (Dikmen et al., 2005). Construction enterprises that have invested in developing long-term, trust-based relationships with supply chain partners typically find these relationships provide substantial value during crises. Conversely, firms that have maintained purely transactional, price-focused relationships may discover that partners prove unwilling to provide accommodation or flexibility when difficulties arise. Strategic relationship management should therefore emphasize quality, reliability, and mutual benefit rather than focusing exclusively on cost minimization.

7.2 Financial Institution Partnerships

Relationships with banks, bonding companies, and other financial institutions prove particularly critical during crisis periods. Financial partners who have deep knowledge of a construction enterprise's operations, leadership team, and track record are more likely to provide continued support during temporary difficulties compared to institutions with superficial relationships (FMI Corporation, 2016). This support may include covenant waivers, temporary credit limit increases, forbearance on defaults, or restructured repayment terms that enable firms to navigate crises without catastrophic disruption. Construction enterprises should therefore view financial relationships as strategic partnerships requiring sustained attention and transparency rather than merely transactional arrangements to be switched based on marginal pricing differences. Regular communication, comprehensive financial reporting, and demonstrated commitment to prudent financial management build trust that proves invaluable during challenging periods.

7.3 Industry Association Participation

Active participation in industry associations provides construction enterprises with access to valuable resources during crises including market intelligence and trend analysis, best practice sharing regarding crisis response strategies, advocacy regarding regulatory issues and government support programs, networking opportunities that can yield project leads or partnership opportunities, and collective bargaining power when addressing industry-wide challenges (Aon, 2024). While industry association participation requires time and financial commitment, the benefits often prove substantial during crisis periods when access to information, resources, and collective voice becomes particularly valuable. Construction enterprises should view industry engagement as a component of their overall crisis preparedness strategy rather than an optional activity.

8. Regulatory and Institutional Framework

The legal, regulatory, and institutional environment within which construction enterprises operate significantly influences their crisis vulnerability and management effectiveness. Regulatory frameworks can either facilitate crisis resilience through supportive policies and flexible requirements, or exacerbate challenges through rigid requirements and inadequate support mechanisms.

8.1 Regulatory Compliance and Risk Management

Construction enterprises face extensive regulatory requirements spanning safety standards, environmental protection, building codes, labor laws, licensing requirements, and contract regulations. While these regulations serve important public interest objectives, they also create compliance costs and can reduce operational flexibility during crises (Allianz Trade, 2024). Understanding regulatory requirements and maintaining robust compliance systems helps construction firms avoid legal liabilities that could compound crisis challenges. During crisis periods, some regulatory authorities provide flexibility through temporary waivers, expedited approvals, or relaxed enforcement to help industries manage extraordinary circumstances. Construction enterprises should maintain productive relationships with regulatory agencies and participate in policy discussions to advocate for appropriate regulatory responses during crises.

8.2 Government Support Programs

Government crisis response programs can provide critical support to construction enterprises through infrastructure investment initiatives, tax relief measures, loan guarantee programs, workforce training subsidies, or direct financial assistance. Awareness of available programs and ability to access them effectively requires attention to program eligibility requirements, application processes, and compliance obligations (Gould Construction Institute, 2025). Construction enterprises should develop capabilities for monitoring government policy developments and rapidly responding to support program opportunities. This may require maintaining relationships with government officials, engaging industry associations for policy advocacy, and establishing internal processes for efficient program application and administration.

8.3 Bankruptcy and Restructuring Frameworks

Legal frameworks governing bankruptcy and corporate restructuring significantly influence crisis management options available to construction enterprises facing financial distress. Well-designed bankruptcy laws can provide opportunities for viable businesses to reorganize, restructure obligations, and emerge from temporary difficulties as sustainable operations. Poorly designed frameworks, conversely, may force liquidation of businesses that could potentially recover (Preprints.org, 2024). Construction enterprises should understand the insolvency frameworks operating in their jurisdictions and consider proactive engagement with restructuring

professionals when early warning signs of financial stress emerge. Early intervention often provides more options and better outcomes than waiting until crisis situations become acute.

9. Integrated Crisis Management Framework

The preceding analysis demonstrates that crisis management effectiveness in construction enterprises depends upon multiple interrelated factors spanning external environmental forces, internal organizational capabilities, stakeholder relationships, and institutional contexts. Effective crisis management requires integrated approaches that address these dimensions holistically rather than treating them as independent issues.

9.1 Proactive Preparedness and Early Warning Systems

Research consistently emphasizes the value of proactive crisis preparedness over reactive crisis response (Hällgren and Wilson, 2008). Construction enterprises should develop comprehensive crisis management plans that address potential scenarios including economic downturns, major project failures, safety incidents, financial distress, supply chain disruptions, and regulatory changes. These plans should identify early warning indicators, establish decision-making protocols, define communication procedures, and clarify roles and responsibilities. Early warning systems that monitor both external environmental conditions and internal organizational performance metrics enable construction enterprises to recognize emerging crisis situations and implement timely responses before problems escalate beyond control. Effective early warning requires establishing relevant metrics, continuous monitoring procedures, clear escalation thresholds, and organizational cultures that reward early identification of problems rather than punishing bearers of bad news.

9.2 Adaptive Capacity and Organizational Learning

Crisis management effectiveness depends not only on planned responses to anticipated scenarios but also on adaptive capacity—the ability to respond creatively to unexpected situations and evolving challenges. Organizational learning mechanisms that capture lessons from past difficulties, analyze performance during crisis events, and incorporate insights into improved policies and practices enable continuous enhancement of crisis management capabilities (Chih et al., 2022). Construction enterprises should establish formal processes for post-crisis analysis and learning, documenting what worked well, what proved ineffective, what surprised the organization, and what should be done differently in future situations. This learning should be systematically incorporated into updated crisis management plans, training programs, and organizational knowledge bases.

9.3 Stakeholder Communication and Transparency

Effective communication with stakeholders—including employees, clients, suppliers, financial institutions, and regulators—plays a critical role in crisis management. Research on crisis communication emphasizes the importance of timely transparency, acknowledging difficulties honestly, explaining response strategies clearly, and maintaining frequent updates as situations evolve (Hinsberg and Lamanna, 2024). Construction enterprises that communicate effectively during crises typically maintain stronger stakeholder relationships, experience greater cooperation from partners, and preserve reputational capital better than organizations that fail to communicate or that provide misleading information. Communication strategies should be integral components of crisis management planning rather than afterthoughts when problems emerge.

10. Conclusion

This analysis demonstrates that crisis management in construction enterprises is a complex, multidimensional challenge requiring integrated strategies across financial, strategic,

organizational, and institutional domains. Construction firms are particularly vulnerable due to cyclical demand, project-based operations, extensive stakeholder networks, and high capital intensity, with these weaknesses becoming more pronounced during crisis periods. The findings highlight several key determinants of effective crisis management. Financial capacity, including liquidity management, capital structure, and cost control, forms the foundation of organizational resilience. Strategic adaptability and market positioning further enable firms to sustain revenues during downturns through diversification, service differentiation, and strong client relationships. Systematic risk governance frameworks support proactive identification and mitigation of emerging threats before they escalate.

Human capital emerges as a critical factor shaping crisis responses. Leadership quality, workforce flexibility, organizational culture, and employee resilience strongly influence how firms adapt to adverse conditions. Enterprises that continue investing in human capital during crises tend to recover more effectively and strengthen their competitive positions. In addition, strong partnership networks with suppliers, subcontractors, financial institutions, and industry stakeholders provide access to resources, facilitate risk sharing, and enhance collective resilience. The regulatory and institutional environment also plays a significant role in shaping crisis management outcomes. Supportive policies, flexible regulations, and effective insolvency mechanisms can expand firms' strategic options during crises. Overall, effective crisis management requires a holistic approach that integrates financial resilience, strategic flexibility, risk governance, human capital development, and collaborative relationships. Future research should adopt longitudinal and comparative perspectives to assess how these factors interact across different crisis types, institutional contexts, and economic cycles, as the need for robust crisis management capabilities continues to intensify in an increasingly volatile construction environment.

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THE ROLE OF COMMERCIAL BANKS IN STIMULATING INVESTMENT ACTIVITY: EVIDENCE FROM UZBEKISTAN

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Abstract. *The banking sector plays a pivotal role in stimulating investment activity and ensuring sustainable economic growth, particularly in emerging economies. Over the past decade, Uzbekistan has undertaken large-scale financial reforms aimed at strengthening the banking system, enhancing financial intermediation, and increasing investment flows into the real sector of the economy. This study analyzes the current state of investment activity in Uzbekistan's banking sector during the period 2020–2024, focusing on asset dynamics, credit expansion, deposit growth, and investment strategies of major commercial banks. Using official data from the Central Bank of Uzbekistan, international financial institutions, and case studies of leading banks such as Asaka Bank, Ipoteka Bank, and the National Bank for Foreign Economic Activity (NBU), the research identifies key trends, structural transformations, and existing constraints in bank-led investment financing. The findings indicate a significant increase in long-term lending, improved asset quality, rising profitability, and growing participation of banks in infrastructure, industrial, and housing projects. However, challenges remain in terms of portfolio diversification, regulatory barriers, underdeveloped capital markets, and limited access to finance for small and medium-sized enterprises (SMEs). The paper concludes that further development of capital markets, digital financial technologies, risk management systems, and public–private partnership mechanisms is essential to enhance the investment potential of the banking sector and ensure sustainable economic modernization in Uzbekistan.*

Keywords: *banking sector, investment activity, commercial banks, Uzbekistan, financial reforms, economic growth.*

Introduction

Investment activity is a fundamental driver of economic growth, structural transformation, and technological modernization. In emerging economies, where capital markets are often underdeveloped, commercial banks play a dominant role in mobilizing financial resources and channeling them into productive investments. Uzbekistan represents a notable case of banking sector transformation, characterized by rapid institutional reforms, liberalization policies, and increasing integration into the global financial system.

Since 2017, Uzbekistan has implemented comprehensive reforms aimed at strengthening its banking sector, improving corporate governance, reducing state dominance, and enhancing transparency. These reforms have significantly altered the role of banks, transforming them from passive financial intermediaries into active institutional investors supporting industrialization, infrastructure development, and innovation.

This study aims to examine the contemporary state of investment activity in Uzbekistan's banking sector, assess its impact on the investment process, and identify key challenges and

prospects for further development. The research contributes to the existing literature by providing an updated empirical analysis based on recent data and bank-level case studies.

Literature Review

The relationship between banking sector development and investment activity has been extensively examined in economic literature. According to classical financial intermediation theory, banks reduce transaction costs, mitigate information asymmetries, and allocate capital more efficiently (Levine, 2005). In developing economies, banks often substitute for underdeveloped capital markets, becoming the primary source of long-term investment financing.

Empirical studies suggest that a well-capitalized and diversified banking system positively influences investment growth and economic stability (Beck & Levine, 2004). In transition economies, banking reforms and privatization have been shown to enhance investment efficiency, provided that regulatory frameworks and risk management systems are adequately developed.

Recent studies on Central Asia emphasize the growing role of banks in financing infrastructure and industrial projects, while highlighting persistent challenges such as state dominance, weak capital markets, and limited SME access to finance. This research builds upon these findings by focusing specifically on Uzbekistan's recent banking reforms and investment outcomes.

Methodology and Data. This study adopts a comprehensive methodological framework that combines quantitative statistical analysis with qualitative case study approaches in order to provide an in-depth assessment of investment activity within Uzbekistan's banking sector. Such a mixed-methods design allows for both macro-level evaluation of sector-wide trends and micro-level examination of individual banks' investment strategies, ensuring robustness and analytical depth.

Research Design. The research is structured as an empirical descriptive and analytical study focusing on the period **2020–2024**, which represents a crucial stage in the transformation of Uzbekistan's banking system. This timeframe captures the effects of post-pandemic recovery, intensified financial sector reforms, and increased integration of international banking standards.

The study is guided by the following analytical objectives:

- to examine the dynamics of banking assets, credit portfolios, and deposit bases;
- to assess the role of commercial banks in financing long-term investment projects;
- to evaluate the effectiveness of banks' investment policies using profitability and risk indicators;
- to identify structural constraints limiting investment activity and propose policy-oriented solutions.
- Data Sources

The empirical analysis is based on **official, verified, and publicly available data**, ensuring reliability and academic validity. The primary data sources include:

- **Central Bank of the Republic of Uzbekistan (CBU)**: annual reports, statistical bulletins, and banking sector indicators, including assets, capital, credit portfolios, non-performing loans (NPLs), and profitability ratios.
- **Ministry of Economy and Finance of Uzbekistan**: investment statistics and macroeconomic indicators.
- **Annual and financial reports of major commercial banks**, including Asaka Bank, Ipoteka Bank, National Bank for Foreign Economic Activity (NBU), Aloqabank, and Xalq Bank.

- **International financial institutions**, such as the European Bank for Reconstruction and Development (EBRD), the World Bank Group (IFC), OECD, and Asian Development Bank (ADB), which provide comparative assessments, policy reviews, and institutional evaluations.

The use of both national and international data sources enhances cross-validation and allows for benchmarking Uzbekistan's banking investment activity against regional and international trends.

Quantitative Methods

Quantitative analysis focuses on the measurement of investment-related indicators and their dynamics over time. The following methods are applied:

- **Trend analysis**, used to examine changes in banking assets, credit volumes, and deposits over the selected period.
- **Structural analysis**, employed to assess the composition of bank assets, credit portfolios by sector, and forms of investment financing.
- **Ratio analysis**, including Return on Assets (ROA), Return on Equity (ROE), credit growth rates, and NPL ratios, to evaluate financial performance and investment efficiency.
- **Comparative analysis**, allowing for cross-bank and intertemporal comparisons among leading commercial banks.

All monetary indicators are analyzed in nominal terms as reported by official sources, ensuring consistency across datasets.

Qualitative Case Study Approach

To complement the quantitative findings, the study applies a **case study methodology** focusing on selected systemically important banks. These banks were chosen based on their asset size, market share, and strategic role in investment financing.

The case studies analyze:

- sectoral priorities of investment portfolios;
- participation in infrastructure, industrial, housing, and digital projects;
- adoption of innovative investment instruments, including green bonds and ESG-based financing;
- cooperation with international financial institutions and public–private partnership mechanisms.

This approach enables the identification of best practices and institutional differences in investment behavior across banks.

Analytical Limitations. While the study provides a comprehensive overview of banking investment activity, several limitations should be acknowledged. First, the analysis relies primarily on aggregated banking data, which may mask intra-bank heterogeneity. Second, limited availability of detailed project-level data restricts the application of advanced econometric modeling. Finally, the evolving regulatory environment may influence investment outcomes beyond the observed period. Despite these constraints, the chosen methodology provides a reliable and systematic basis for evaluating the role of commercial banks in stimulating investment activity and supports evidence-based policy conclusions.

Current State of the Banking Sector and Its Impact on Investment

Structural Transformation of the Banking Sector

Uzbekistan's banking system operates under a two-tier structure, with the Central Bank responsible for regulation and supervision, and commercial banks providing financial services to

the economy. As of 2024, the country had 33 operating banks, including state-owned, private, and foreign-capital institutions. Total banking assets exceeded 640 trillion Uzbek soums, reflecting a 42% increase compared to 2020. The asset structure reveals a strong emphasis on credit operations, which account for approximately 76% of total assets. This indicates a credit-oriented financial model in which banks play a central role in investment financing rather than portfolio investment in securities.

Macroeconomic Environment and Investment Conditions

Macroeconomic stability has been a key factor supporting investment activity. During 2020–2024, Uzbekistan's GDP grew at an average annual rate of 5.6%, while inflation declined significantly. This allowed for a more accommodative monetary policy and reduced borrowing costs, thereby stimulating long-term investment lending.

Dynamics of Assets, Credits, and Deposits

Asset and Credit Growth

Between 2020 and 2024, the total credit portfolio of banks expanded from 340 trillion to 490 trillion soums, representing a growth of approximately 44%. The increase was particularly pronounced in industrial production, construction, infrastructure, and agriculture—sectors closely linked to investment activity. The share of long-term loans rose to 56% of total credit portfolios, underscoring the increasing role of banks in financing capital-intensive projects.

Deposit Base and Financial Stability

Deposits remain the primary funding source for banks. Over the analyzed period, household deposits nearly doubled, reflecting increased public confidence in the banking system. At the same time, the share of foreign-currency deposits declined, indicating gradual de-dollarization and improved macroeconomic credibility.

Investment Policies of Commercial Banks: Case Studies

Asaka Bank. Asaka Bank has emerged as a leading investor in industrial and infrastructure projects, particularly in the automotive and energy sectors. Its investment portfolio demonstrates strong diversification, with increasing attention to digitalization and ESG-oriented projects.

Ipoteka Bank. Ipoteka Bank specializes in housing finance and urban development projects. Its investment volume more than doubled between 2020 and 2024, reflecting the expansion of mortgage programs and infrastructure financing.

Other Banks. NBU focuses on export-oriented investments and large infrastructure projects, while Aloqabank and Xalq Bank emphasize digital innovation and social investment, respectively. Together, these institutions form a multi-layered investment financing model within the banking sector.

Challenges and Constraints

Despite notable progress, several challenges constrain the investment potential of banks:

- Limited diversification of investment instruments
- Underdeveloped capital markets
- Regulatory complexity and compliance costs
- Insufficient risk assessment tools for innovative projects
- Restricted SME access to long-term finance

These issues reduce flexibility and limit banks' ability to support high-risk, high-return investment initiatives.

Conclusions. This study has examined the contemporary role of commercial banks in stimulating investment activity in Uzbekistan during the period 2020–2024, a critical phase of

financial sector transformation and economic modernization. The findings demonstrate that the banking sector has evolved from a predominantly intermediary-based system into an increasingly active institutional investor, playing a central role in channeling financial resources toward long-term development objectives. The empirical analysis reveals a sustained expansion of banking assets, credit portfolios, and deposit bases, accompanied by improvements in profitability and asset quality. In particular, the growing share of long-term loans and the declining ratio of non-performing loans indicate enhanced financial discipline and more effective risk management practices. These trends confirm that commercial banks have become key drivers of investment financing in strategic sectors such as industry, energy, infrastructure, housing construction, and agriculture. Case studies of leading banks, including Asaka Bank, Ipoteka Bank, and the National Bank for Foreign Economic Activity, highlight a gradual diversification of investment strategies. Banks increasingly participate in large-scale infrastructure projects, export-oriented initiatives, housing programs, and digital transformation efforts. The introduction of innovative instruments-such as green bonds, ESG-based project evaluation, and syndicated lending- further illustrates the modernization of investment policies within the banking sector.However, despite these positive developments, the study identifies several persistent structural constraints. Investment portfolios remain highly concentrated in traditional credit instruments, while capital market-based financing, venture investments, and project finance mechanisms are underdeveloped. Regulatory complexity, limited risk assessment tools for innovative projects, and insufficient access to long-term funding-particularly for small and medium-sized enterprises-continue to constrain the full realization of banks' investment potential.

Overall, the results suggest that while Uzbekistan's banking sector has made substantial progress in supporting investment-led growth, its long-term effectiveness will depend on deeper institutional reforms, enhanced market diversification, and stronger integration with global financial practices.

Policy Implications. Based on the findings of this study, several policy implications can be formulated to strengthen the role of commercial banks in fostering sustainable investment activity and economic development.

First, **the development of capital markets should be prioritized** to complement bank-based financing. Expanding the market for government and corporate bonds, encouraging initial public offerings, and supporting investment funds would reduce excessive reliance on bank credit and improve risk diversification. A more developed capital market would also enable banks to rebalance their portfolios and access long-term funding sources.

Second, **regulatory and institutional frameworks should be further streamlined** to facilitate investment banking activities. Simplifying licensing procedures for new financial instruments, reducing administrative barriers for project finance, and enhancing regulatory predictability would accelerate investment decision-making and reduce transaction costs for banks and investors.

Third, **risk management and analytical capacity within banks must be strengthened**. This includes the wider adoption of advanced credit scoring models, stress testing, big data analytics, and artificial intelligence-based risk assessment tools. Improving project evaluation methodologies is particularly important for innovative, digital, and green investment projects that do not fit traditional collateral-based lending models.

Fourth, **access to finance for small and medium-sized enterprises should be expanded** through targeted policy measures. Government-backed guarantee schemes, co-financing

mechanisms, and subsidized credit programs can reduce perceived risks and encourage banks to increase investment lending to SMEs. Enhancing financial transparency and accounting standards among SMEs would further support this process.

Fifth, **the promotion of ESG and sustainable finance initiatives should be intensified**. Encouraging green bonds, sustainable investment funds, and environmentally responsible lending practices would not only attract international capital but also align the banking sector with global sustainability goals. Banks should be incentivized to integrate environmental and social criteria into their investment decision-making frameworks.

Finally, **public–private partnership (PPP) mechanisms should be expanded** to mobilize private capital for large-scale infrastructure and social projects. Banks can play a coordinating role in structuring PPP financing, managing risks, and ensuring the efficient allocation of resources.

Final Remarks. In conclusion, the banking sector in Uzbekistan has emerged as a cornerstone of the country's investment and development strategy. Continued progress, however, will require a balanced approach that combines financial stability with innovation, regulatory discipline with flexibility, and state support with market-driven incentives. By advancing these policy directions, Uzbekistan can further enhance the contribution of its banking sector to sustainable economic growth, investment efficiency, and long-term competitiveness.

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WAYS TO IMPROVE THE MARKETING SERVICE SYSTEM IN INDUSTRIAL ENTERPRISES

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Abstract. *This article examines the complexity of the furniture production process and the high impact of technology, the fact that the production of modern furniture requires sophisticated technologies, the production of new types and models of furniture, the long-term service of consumers from the product, and the fact that consumers spend a relatively large amount of time on the selection and purchase process of goods.*
Keywords: *furniture products, consumer, assortment, service, process, price, technology.*

Introduction. Market research is a comprehensive analysis of the current state of the market, including an assessment of demand, supply, price trends and the competitive environment. In Uzbekistan, against the backdrop of active economic reforms and updating the legislative framework, market research is of particular importance for effective strategic planning and management decision-making. In recent years, the country has been implementing the "Development Strategy of New Uzbekistan for 2022-2026", aimed at comprehensive modernization of the economy and society. Within the framework of this strategy, special attention is paid to creating favorable conditions for entrepreneurial activity, developing market relations and ensuring fair competition. These areas are reflected in the updated version of the Law "On Competition" (ZRU-850) dated July 3, 2023.

The new Law "On Competition" introduces the concept of antitrust compliance, revises the conditions for determining a dominant position in the market and establishes new criteria for economic concentration transactions. These changes are aimed at preventing market monopolization, supporting small and medium-sized businesses, and protecting consumer rights. The introduction of these standards requires market participants to carefully analyze and adapt their strategies in accordance with the new rules.

In addition, in October 2023, the Presidential Decree "On additional measures for accelerated industrial development" (UP-169) was adopted. The document provides for the development of proposals and comprehensive measures based on a study of market conditions to meet the needs of the domestic market and prevent sharp price fluctuations. This emphasizes the importance of systematic monitoring and analysis of market conditions to ensure stability and sustainable development of the economy. Thus, in the context of updating the legislative framework and implementing strategic initiatives, studying the market situation in Uzbekistan is becoming an integral element of effective management and planning. A comprehensive analysis of market conditions allows for timely identification of trends, adaptation to changes and making informed decisions that contribute to the sustainable development of business and the economy as a whole.

Analysis of literature on the topic. Based on foreign experiences, it should be noted that the competitiveness of the enterprise in the market is determined by the effectiveness of its market-

oriented policy. Many economists have been engaged in the development of marketing principles and their practical application, including F. Kotler, M. Porter, D. Evans, I. Ansoff, M. Berman, M. Golubkov, P. Samuelson, D. .We can include famous scientists like Marshall.

It is necessary to acknowledge the scientists who made a great contribution to the development of the theory of marketing, while the research carried out in the field of marketing in our country for many years was based on national characteristics. R. Ibragimov to them. Y. Abdullaev, A. Saliev, M. Sharifkhojaev, D. Rakhimova, SH. Ergashkhodjaeva, Sh. Musayeva and others can be included.

Research methodology. The study used a systematic approach, marketing analysis, benchmarking, and digital metrics. Mass surveillance methods were used to collect and analyze data from social media platforms.

Analysis and results. The marketing activities of "GULOBOD" LLC are similar to those of all furniture enterprises in the region. In this case, market research, organization of product policy, pricing and sales promotion schemes depend on the initiative and capabilities of the enterprise. We can see this from the data in the table below (table).

Table 1

Analysis of the sales network at "GULOBOD" LLC in 2024

t/r	Name of the points of sale	Sales volume, pcs.	Sales volume, million soums
1	Navobod Dier Store	2339	3101.0
2	Dealer in store	324	679.3
3	Bukhara dealer store	46	103.0
4	Shop Tashkent Dier	128	377.1
5	Store Fergana dealer	11	94.8
6	OOO "Havas Comfort Furniture"	108	76.1
7	Sam-Karpo Design Dealer	2328	3260.3
8	F-2 orders	5836	1688.7
9	F-3 orders	129	29.9
10	Individuals	201	640.8
11	Legal entities	2740	1644.7
	Total	**14190**	**11695.8**

Table 2

Structure of sales volume at "GULOBOD" LLC in 2024

t/r	Name of the points of sale	Sales volume, pcs.	Sales volume, million soums
1	Selling furniture products through dealers	5284	7691.6
2	Spare parts for furniture	5965	1718.7
3	Individuals	201	640.8
4	Legal entities	2740	1644.7
	Total	14190	11695.8

According to the results of the study, it was necessary to study some of our national characteristics in the implementation of furniture product marketing. That is, it turned out that the

possibility and effectiveness of marketing application significantly depends on the type of market, the products being produced and sold, and the scale of competition in the market. In particular, the lack of universal, standard, unified recommendations in the application of the marketing concept is significant, and in practical marketing everything depends on external and internal factors, consumer characteristics. If 5-6 years ago in Uzbekistan the "total" approach prevailed in the application of the marketing concept, now the differentiated approach is widely used. If we analyze the furniture products produced by type of content, 58 percent is household furniture, 39 percent is institutional furniture, and three percent is other furniture. A significant share in this regard is office furniture and special furniture for educational institutions, retail stores, hospitals, restaurants, shops, warehouses, hairdressing salons, etc.

Analysis of the structure of furniture production by region showed that the main part of the furniture produced in 2024 was sold to the city of Samarkand and the region. The share of sales by region was as follows: to the city of Tashkent -377.1 million soums, to Fergana region -94.8 million soums, to the city of Karshi679.3 million soums, to the city of Bukhara - 103.0 million soums.. As noted above, the sustainable development of any industry is directly related to the production and sale of goods that are in demand. This, in turn, requires the effective organization of marketing activities of industry enterprises, regular research of the furniture market, taking into account consumer preferences, and a detailed analysis of the factors of the purchasing process. Technological change, the increasing role of social media, demographic changes, and the increase in women's purchasing power are the main aspects that should be taken into account in the marketing work of furniture manufacturers and retailers. We found it appropriate to segment our country's furniture consumers based on history, culture, customs, traditions, and the nature of furniture products. **"GULOBOD"** If we observe the activities of the LLC, from the time of its establishment to the present day, a wide range of goods occupies the main part of the assortment. From this it can be concluded that these two furniture manufacturing enterprises are applying certain differentiation strategies in terms of specialization.

Table 3

Features of the product range of "GULOBOD MEBEL" LLC

"HAVAS COMFORT FURNITURE" LLC	**"GULOBOD FURNITURE" LLC**
Targeted at middle and low-income buyers	Targeted at middle and high income buyers
The assortment mainly includes kitchens and upholstered furniture.	A wide range of products has been formed
The furniture is made using standard technology and has a low level of differentiation.	The furniture is made in a modern individual style, guaranteed to meet all types of samples in the catalog.
Orders for any furniture repair are accepted.	Does not repair furniture (except during the warranty period)
There is a possibility and orders for the production of components	No spare parts are produced.
Individual items of furniture sets are also produced.	Only orders are created for collections
The trademark has not been formed.	Produces products under the MONDELUX trademark

From the above analysis, it is clear that “HAVAS COMFORT MEBEL” LLC and “GULOBOD MEBEL” LLC specialize in separate segments of the furniture market and together try to cover the market. When purchasing furniture, consumers use a wide range of information, i.e.: they analyze various information, try to find the optimal purchase option, choose a product based on their lifestyle, taste and capabilities. The consumer also takes into account financial, technical, time loss and psychological risks when purchasing a long-term product.

The buyer performs the actions of purchasing and using home appliances only after clarifying his need, which consists of several interconnected stages. That is, the overall need is focused on solving the following problems:

● determines what type of furniture will fully meet his needs;

● The product is sold from the market, the company isbuys from the mine or via the internet;

● What are the advantages of the product, what warranty does the seller provide, and how long can this product be used?

To what extent do media influence the purchase of furniture? The analysis shows that when purchasing home appliances, 52.5% of the population uses television programs, 43.1% uses newspaper and magazine advertisements, 49.7% visits company stores, and 50.6% uses catalogs and brochures. Furniture manufacturers need to improve the positioning process in order to achieve competitive advantage and ensure a stable position for their products in the target market and in the minds of consumers, clearly different from competitors' products. Enterprises in this industry are directing significant efforts in implementing marketing activities to the formation of a marketing complex. As a result, the positioning process, which plays an important role in the systematic and effective conduct of marketing activities by enterprises, is lagging behind. When positioning a product, special attention should be paid to developing customer awareness and modernizing it.

Improper organization of the positioning process in furniture manufacturing companies can lead to the following negative consequences:

– If the manufacturer does not determine the position of the product in the market, in this case the consumer can perform this task himself, and the company may not be able to achieve the position it expects, and may even lead to the formation of a negative image;

– Failure to clearly indicate the product's unique features that distinguish it from competitors' products, or positioning it close to competitors' positions, may serve to discourage consumers from purchasing the product, rather than to motivate them to do so;

– The lack of a clear positioning of the product can hinder the formation and consistency of the marketing mix, and may even lead to conflicting strategies for forming each element of the marketing mix.

– Even if the position is clearly chosen, but if its boundaries are narrowly defined, such positioning can act as a force that hinders the expansion of the market for the company's existing products and the introduction of new products. The main reason for this is that companies in the industry use a common brand strategy.

Based on the above, furniture manufacturers should focus on two main areas when implementing the positioning process:

– Determining the point of relevance or, in other words, the point of similarity of the positioned product. That is, based on research, it is intended to determine in the minds of consumers which product category the enterprise's product is equated with, or rather, which

category it is included in. This, in turn, makes it possible to identify its direct competitors based on revealing the specific characteristics of the product category.

– Identifying the point of differentiation of the positioned product. This involves demonstrating the competitive advantage of the product by identifying one or more unique features that clearly distinguish it from competitors' products.

– Furniture manufacturers should consider the following specific features of the industry before positioning themselves in the above-mentioned areas:

– The complexity of the product production process and the high impact of technology. The production of modern furniture requires sophisticated technologies, which ultimately leads to an increase in the market price of the product.

– The length of the period for launching the production of a new type and model of furniture. The average period for launching the production of a new model of furniture for large furniture manufacturers is 7-15 months.

– High demand for product quality. Since furniture is a type of product that requires prior selection, consumers expect the product to provide long-term service. In order to maintain the quality of their products at a high level, manufacturers use high-quality fittings in their production, while maintaining their functional properties. Therefore, many companies use the words “quality” and “durable” when positioning their products. Warranty service. Usually, the costs of warranty and post-warranty service are not high, but in some cases they can amount to 20-25% of the product cost. Also, after-sales furniture assembly service can be up to 10% of the product cost. The consumer spends a relatively large amount of time on the product selection and purchase process. Marketing research shows that in the consumer goods market, a consumer can spend up to 4 weeks on selecting and purchasing furniture. The above problems and the specifics of marketing activities in furniture production highlight the need for enterprises to develop a strategic and tactical program for a separate marketing service.

Conclusion and suggestions. Being aware of market trends and consumer demands in Uzbekistan is essential to expanding the company’s position and position in the furniture market. By adopting sustainable practices, offering traditional designs, having a strong online presence, and using natural and organic materials, Gulobod LLC can address current market trends in Uzbekistan and expand its position in the market. Analyzing statistical data and understanding market trends, conducting research and analysis, innovating products, and collaborating with local designers and craftsmen also provide the company with ample opportunities to gain a competitive advantage, succeed in this dynamic industry, and achieve long-term success in the market. We offer the following methods for studying different consumer behavior patterns and their application to Gulobod LLC in the furniture industry:

1. Surveys. Surveys are one of the most common and effective ways to study consumer behavior, and developing effective survey methods is essential to collecting reliable data. Surveys can be conducted both online and in person, and they are used to collect quantitative data on topics such as shopping habits, product preferences, and brand loyalty.

2. Focus groups. Focus groups are another effective way to study specific consumer behaviors in Uzbekistan. Focus groups typically consist of a small group of consumers who are asked to discuss their opinions and attitudes toward a particular product or service. Focus groups can provide qualitative data on topics such as product design, packaging, and pricing.

3. Online analysis. In today's digital age, online analytics has become an increasingly important tool for studying specific consumer behaviors. Online analytics is the process of

obtaining valuable insights into consumer behavior by monitoring consumers' interactions with a company's website, social media accounts, and other online platforms. Online analytics also involves collecting and analyzing data related to online user behavior, such as website traffic, user engagement, and online purchases.

Understanding the unique behavior of consumers is crucial for any business operating in Uzbekistan, especially Gulobod LLC, which produces yarn and textile products for the domestic market and export. Surveys, focus groups, ethnographic research, and online analytics are effective methods for studying consumer behavior and provide valuable insights into consumer preferences and attitudes. By using these methods, a company can tailor its products and services to the unique requirements of the Uzbek market and achieve long-term success.

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FORMATION OF ECONOMIC ADVANTAGES OF BUSINESS IN THE CONTEXT OF MANAGEMENT DIGITAL TRANSFORMATION

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Abstract. *This article provides a comprehensive analysis of the theoretical and practical aspects of digital transformation processes in business management under the conditions of globalization, the digital economy and rapid technological development. The dynamic advancement of modern digital technologies has become a key factor in organizing business activities, improving management mechanisms, and enhancing economic efficiency. The study highlights the role of digital transformation in optimizing business processes, reducing management costs, increasing labor productivity, and fostering an innovative environment. Furthermore, the article examines the improvement of the accuracy and efficiency of managerial decision-making through the implementation of information and communication technologies, digital platforms, artificial intelligence, cloud technologies, and data analytics tools in management systems. Digital transformation enables enterprises to quickly adapt to market demands, strengthen customer relationships, and create new competitive advantages. The research findings indicate that a consistent and strategically grounded implementation of digital transformation processes contributes to ensuring the sustainable economic development of business entities. The conclusions confirm that digital transformation should be considered a crucial strategic resource in modern business management.*

Keywords: *digital transformation, business management, economic advantages, competitiveness, digital economy, globalization.*

Introduction

In the contemporary global economy, digital transformation has become one of the most influential drivers of structural change in business management. Rapid technological progress, the diffusion of digital platforms, and the increasing importance of data have fundamentally altered the competitive landscape across industries. Enterprises now operate in an environment characterized by heightened uncertainty, shortened product life cycles, intensified global competition, and continuously evolving consumer expectations. Under such conditions, traditional management models based on rigid hierarchies and linear decision-making processes often fail to ensure sustainable development and long-term competitiveness.

Digital transformation of management represents not merely the adoption of advanced information technologies, but a profound rethinking of managerial philosophy, organizational design, and strategic priorities. It involves the integration of digital tools into planning, control, coordination, and decision-making processes, thereby transforming how value is created and captured. The increasing reliance on automation, real-time data analytics, and digital platforms has redefined the sources of economic advantage in modern business.

For developing and transition economies, including Uzbekistan, management digital transformation has particular strategic importance. It enables enterprises to overcome structural constraints, integrate into global value chains, improve transparency, and enhance operational efficiency. Consequently, the formation of economic advantages through management digital transformation becomes a critical factor for both firm-level competitiveness and national economic development. This study aims to explore the mechanisms, theoretical foundations, and practical implications of economic advantage formation in the context of management digital transformation.

Literature Review

The concept of digital transformation has been extensively examined in contemporary economic and management literature. Scholars generally agree that digital transformation constitutes a systemic and multidimensional process affecting business models, organizational culture, and managerial decision-making. Porter and Heppelmann argue that digital technologies transform competition by reshaping value chains, blurring industry boundaries, and creating new sources of differentiation. From this perspective, management digital transformation becomes a central determinant of competitive dynamics.

Bharadwaj et al. emphasize that digital business strategy is not a functional extension of information technology strategy but an integral component of overall corporate strategy. Digital technologies enable firms to develop unique organizational capabilities that serve as sources of sustainable competitive advantage. Other researchers highlight the role of big data analytics, artificial intelligence, cloud computing, and enterprise digital platforms in enhancing managerial efficiency and reducing transaction costs. At the same time, empirical studies demonstrate that the economic outcomes of digital transformation are highly context-dependent. Organizational readiness, leadership quality, human capital, and institutional environment significantly influence the effectiveness of digital initiatives. In emerging economies, limited digital infrastructure and skills shortages may constrain the realization of economic benefits, making effective management digitalization strategies particularly important.

Research Methodology

The methodological framework of this study is based on general scientific methods, including analysis, synthesis, induction, deduction, and logical generalization. A qualitative analytical approach is employed to examine the relationship between management digital transformation and the formation of economic advantages. The research relies on theoretical models from strategic management, digital economy theory, and innovation economics. In addition, analytical reports of international organizations and comparative studies on digital development are used to support the analysis. This approach allows for a comprehensive examination of digital transformation as a complex economic phenomenon and enables the identification of key mechanisms through which management digitalization contributes to economic advantage formation.

Theoretical Framework of Management Digital Transformation

Management digital transformation can be theoretically explained through several complementary economic and management theories. The Resource-Based View (RBV) posits that firms achieve sustainable competitive advantage by possessing resources that are valuable, rare, inimitable, and non-substitutable. Digital managerial capabilities—such as advanced analytics, automated control systems, and platform-based coordination—meet these criteria when effectively embedded in organizational routines.

Dynamic Capabilities Theory further extends this perspective by emphasizing the firm's ability to sense environmental changes, seize emerging opportunities, and reconfigure resources accordingly. Digital technologies significantly enhance these capabilities by accelerating information flows, improving environmental scanning, and enabling rapid strategic adaptation. As a result, digitally mature enterprises demonstrate greater resilience and adaptability under volatile market conditions. Institutional economics provides additional insight, particularly for emerging economies. Digital governance systems reduce transaction costs, increase transparency, and limit opportunistic behavior. Through these mechanisms, management digital transformation contributes to institutional trust and more efficient market coordination.

Digital Transformation and Economic Advantage Formation Mechanisms

Management digital transformation generates economic advantages through several interconnected mechanisms. First, automation of managerial and operational processes reduces labor intensity, minimizes human error, and lowers operational costs. Digital management systems ensure higher accuracy and speed in information processing, directly improving economic efficiency.

Second, digital technologies enhance the quality of managerial decision-making. The use of data analytics, dashboards, and real-time monitoring tools provides managers with timely and reliable information, enabling more accurate forecasting, strategic planning, and resource allocation. This data-driven approach reduces uncertainty and improves organizational performance.

Third, digital transformation strengthens customer orientation. Digital platforms and customer relationship management systems facilitate closer interaction with consumers, allowing firms to better understand customer needs and offer personalized products and services. This leads to increased customer satisfaction, loyalty, and long-term profitability.

Management Digital Transformation and Managerial Efficiency

One of the most significant economic outcomes of management digital transformation is improved managerial efficiency. Integrated digital management systems connect various functional units into a unified information environment, enhancing coordination and control. This integration reduces information asymmetry between organizational levels and improves accountability.

Furthermore, digital tools support decentralized decision-making by granting employees access to relevant information. This increases organizational flexibility and responsiveness to environmental changes, resulting in higher productivity and stronger competitive positions.

Data Analytics and Strategic Decision-Making

The growing importance of data analytics represents a fundamental shift in modern management. By analyzing large volumes of structured and unstructured data, enterprises can identify patterns, assess risks, and evaluate strategic alternatives. Predictive analytics enables firms to anticipate market trends and respond proactively. Firms that successfully develop analytical capabilities gain informational advantages that are difficult for competitors to replicate. These advantages enhance strategic stability and contribute to long-term economic performance.

Digital Platforms and Business Model Innovation

Digital platforms play a central role in transforming traditional business models. Platform-based ecosystems enable direct interaction between producers, consumers, and partners, reducing transaction costs and expanding market reach. Network effects generated by digital platforms enhance scalability and value creation. Moreover, digital platforms support continuous innovation

by enabling rapid experimentation and iterative improvement of products and services. This adaptability strengthens firms' ability to maintain sustainable economic advantages in dynamic markets.

Economic Implications for Emerging Economies: The Case of Uzbekistan

For Uzbekistan and similar transition economies, management digital transformation has strategic macroeconomic significance. It supports economic diversification, development of small and medium enterprises, and integration into global value chains. Government-led digital initiatives and e-government platforms create favorable conditions for private sector digitalization. At the firm level, digital accounting systems, electronic procurement, and digital payment solutions enhance transparency and financial discipline, improving access to external financing. However, challenges related to infrastructure limitations, skills gaps, and uneven adoption remain significant.

Risks and Challenges of Management Digital Transformation

Despite its advantages, management digital transformation involves considerable risks. High initial investment costs, cybersecurity threats, and resistance to organizational change may hinder effective implementation. Inadequate change management can lead to underutilization of digital technologies and reduced economic returns. Therefore, enterprises should adopt a phased and strategic approach to digital transformation, emphasizing employee training, organizational learning, and robust digital governance.

Socio-Economic and Sustainability Dimensions

Beyond firm-level benefits, management digital transformation generates broader socio-economic effects. Increased productivity and competitiveness contribute to economic growth and job creation in high-skilled sectors. Digital inclusion initiatives expand access to markets and services, supporting inclusive development. Digital technologies also promote sustainability by enabling efficient resource use, optimizing logistics, and reducing environmental impact. These sustainability gains reinforce the long-term economic viability of digitalized enterprises.

Conclusion

This study demonstrates that management digital transformation is a foundational driver of economic advantage formation in modern business. Economic benefits arise not from technology adoption alone, but from the strategic alignment of digital technologies with organizational capabilities, human capital, and governance structures. For enterprises in both emerging and developed economies, management digital transformation should be regarded as a strategic imperative. Its effective implementation determines firms' ability to achieve sustainable competitiveness and successfully integrate into the global digital economy.

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THE ECONOMIC IMPACT OF SPACE TOURISM

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Abstract*. This article examines the economic impacts of space tourism, with particular attention to its potential benefits, risks and the environmental impact it has as a result of its rapid growth. The analysis is based on academic literature, industry reports and data and economic assessment that explores the impact of the growth of space tourism on sustainable development, job creation, technological innovation, and economic growth. By comparing both positive and negative results the study identify the key components that affect the development and long-term sustainability of space tourism as a commercial sector. The findings indicate that space tourism creates significant economic prospects through the the creation of highly skilled jobs, opening of new markets, and the attraction of private investment in advanced technologies. At the same time, the industry faces substantial challenges such as high operating costs, volatile demand, limited availability, and environmental issues such as space debris and greenhouse gas emissions. The article examines the current and future economic impacts of space tourism. Finally, the article suggests that space tourism has the potential to play an important role in the world economy, but its long-term success will rely on responsible administration, efficient regulation and continued technological progress.*

Keywords: *economic growth, economic opportunities, environmental impact, industry sustainability, future outlook.*

Introduction

Space tourism is an evolving form of commercial space travel that allows individuals to fly off-Earth for recreation, research, or personal experiences. For most of the twentieth century, such activities were considered purely theoretical and remained the privilege of government space programs. But over the past two decades, space tourism has evolved from a theory to an emerging industry due to technological advances, increased private investment, and the involvement of commercial companies in space travel. There are several different types of space tourism, including orbital and suborbital space tourism. Suborbital flights is the most popular type, which involves brief excursions, typically lasting a few minutes, before returning to Earth. Orbital tourism is another type which allows passengers to remain in orbit, with the opportunity to visit the International Space Station while circling the Earth at a high speed.

Companies such as SpaceX, Virgin Galactic, and Blue Origin have played an important role through the launch of orbital and suborbital flights, making space tourism accessible to both individuals and government organizations. The economic significance of this emerging sector has attracted growing academic attention. Collins (2008) argues that space tourism stimulates new markets, technological innovation, and private investment. However, the industry also faces significant challenges that hinder its development. Building on this outlook, Tkatchova (2010) emphasizes the importance of regulatory frameworks and sustainability, while Atanasov (2010)

highlights the role of financial modeling as a key tool for evaluating the industry's broader economic impact. The rise of space tourism is driving the development of a new commercial space sector that brings significant positive economic impacts, yet it also introduces significant negative economic and environmental effects, making its long-term success dependent on sustainable technologies, effective regulation, and strategic solutions for the industry's future development.

The rise of space tourism

The rise of private space companies has turned space travel into an emerging economic sector. During the 20th century space exploration was possible only on the initiative of the government. However, increased private investment and technological progress have changed this structure. Technological innovations, such as reusable launch vehicles, enhanced propulsion systems, and advanced safety mechanisms, have lowered operational costs and increased the feasibility of commercial flights (Crouch, 2001). These advancements have provided the technical foundation necessary to move space tourism from theoretical discourse to real-world implementation. As a result, private companies now play a dominant role in the industry by providing financially feasible business models and privately supporting infrastructure for both suborbital and orbital flights.

Market analyses suggest that space tourism can attract tens of millions of people worldwide, highlighting the sector's considerable economic potential (Futron Corporation, 2002). The demand for commercial space flights, which also reflects public interest, demonstrates the high economic potential of these flights in the long term. Historical economic studies also predict this trend. Pistor (1989) argues that private participation will transform the space industry into a competitive commercial sector with great economic potential. His analysis emphasizes how crucial market mechanisms are to fostering efficiency and innovation in the sector. Space tourism has become an economically important business due to corporate leadership, technological advances, and growing demand. Its future development will likely depend on continued innovation, market expansion and strategic investments.

Positive economic impacts

Space tourism generates substantial economic benefits, including job creation, innovation, and investment growth. Commercial flights create new opportunities in aerospace engineering, manufacturing, transportation, and travel services. The development and operation of space tourism systems require highly qualified specialists, which leads to the formation of specialized jobs and contributes to the development of the workforce in scientific and technical fields (Autino, 2008). Space tourism not only creates jobs, but also promotes technological innovation. Tkacheva (2010) emphasizes that technological advancements driven by space tourism contribute to economic growth through increased efficiency, sustainability, and cross-industry technological development. These developments attract private investors who are looking for high chances of making a profit in emerging markets. The economic impact of space tourism is further enhanced due to the high costs of travel services. Wealthy travelers often spend on education, accommodation, transportation and other travel-related services, which leads to an increasing in the economy of the region and the country as a whole (Atanasov 2010). Furthermore, the popularity of space tourism stimulates interest in sciences such as technology, mathematics, physics and engineering, contributing not only to economic growth, but also to educational development and long-term innovation.

Negative economic and environmental effect. Despite its advantages, space tourism introduces economic inequalities and environmental risks. One of the most significant economic

issues is limited accessibility. The high cost of flights, reflects the high operational and technological costs associated with the development, maintenance and safety measures of spacecraft. Due to the extremely high cost of space travel, participation remains restricted to wealthy individuals, raising not only economic inequality but also moral questions about whether space tourism can bring broader social benefits (Cohen & Cohen, 2012). Financial instability represents another challenge. Space tourism requires significant initial investment in spacecraft construction, technology, and regulatory compliance, while demand remains uncertain. Crouch (2001), notes that high operating costs combined with market volatility increase the risk of financial losses, particularly during a recession. Additionally, technical failures or accidents could result in severe economic consequences, including legal liabilities, reputational damage, and reduced investor confidence. Environmental impacts further complicate the industry's development. Rocket launches emit greenhouse gasses and soot particles into the upper layers of the atmosphere, which can lead to climate change and atmospheric degradation (Weaver, 2006). The development of space tourism may also contribute to the accumulation of space debris, creating risks for satellites and future missions, and increasing the frequency of launches may worsen the environmental impact. Addressing these economic and environmental challenges is essential for the responsible and sustainable development of space tourism.

Future outlook and solutions. The future of space tourism depends on sustainable technologies and responsible regulation. One promising area involves the use of environmentally friendly rocket fuel and more efficient propulsion systems, which could reduce both emissions and operational costs. Cole (2015) emphasizes that technological innovation plays a crucial role in ensuring the economic and environmental sustainability of the developing tourism sectors. Mass production technologies and reusable spacecraft can reduce costs, ultimately leading to lower cost of spaceflight. Effective regulation is equally important. Governments and international organizations must establish safety standards, environmental regulations, and taxation policies to manage the risks associated with commercial space activities.

Collins (2008) highlights that coordinated international regulation can help minimize environmental damage, reduce financial instability, and promote fair competition between private businesses. International collaboration and public-private partnerships can contribute to further sustainable growth of the industry. Space tourism has great growth potential. Future developments may include space hotels, orbital research facilities and scientific expeditions to the Moon and Mars. According to forecasts by Plog (2001), the expansion of the market will support the demand for innovative and unique travel experiences. With appropriate governance, sustainable technologies, and global collaboration, space tourism has the potential to create new economic opportunities, generate highly skilled employment, and contribute to global economic integration.

Conclusion. Space tourism has emerged as a new commercial space sector that offers significant economic benefits while also creating economic and environmental challenges. This article reviewed the rise of private space companies, the positive impacts of job creation and innovation, and the risks related to high costs, environmental damage, and financial uncertainty. Understanding these dynamics is important because the decisions made by governments and companies today will determine whether space tourism develops into a sustainable and economically valuable industry.

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COMMUNICATION: THE KEY TO GLOBAL TOURISM

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Abstract. *This article is an examination of how communication, cultural, social interaction, and technical development shapes the global tourist industry. Communication through social interaction plays a fundamental role in shaping tourists' emotional reactions, satisfaction, and connection with host communities. To be more precise, by explaining that personal encounters between hosts and visitors create emotional connections that enhance satisfaction and cultural understanding. Wahab explores a technological side, showing how information technology provides accessibility through Tourism by faster decision-making, and improved service delivery. Digital tools, from online booking, help tourists to interact more efficiently. Lukianets highlights a framework for global communication ability, explaining how professionals in tourism, sport, and education develop the intercultural skills necessary for effective communication in an increasingly interconnected world. The analysis shows that effective social and intercultural communication reduces misunderstandings, promotes cultural exchange, and improves visitors' satisfaction. Furthermore, information technology plays an essential role in enhancing global connectivity, decision-making, and service efficiency in tourism. This article concludes that combining intercultural efficiency with technological innovation is crucial for building sustainable tourism environments. These studies highlight that successful tourism depends on social, cultural, and technological communication. Their combined findings suggest that the future of tourism requires both intercultural communication and technological innovation to support sustainable, inclusive, and high-quality travel experience.*

Keywords: *global tourism industry, social interaction, digital tools, tourist satisfaction, cultural exchange, professional communication.*

Introduction

Communication has become a central element of modern tourism, shaping the way people connect, experience cultures, and guide destinations around the world. As global mobility continues to grow, travelers increasingly come into contact with people who have different languages, traditions, and values from their own. Because of this diversity, communication is essential not only for exchanging information but also for building understanding, trust, and positive relationships between tourists and host communities. Social interaction plays a major role in shaping tourist satisfaction, since meaningful conversations and hospitality often affect how visitors perceive a destination. When communication comes harmoniously, travelers feel more confident, respected, and engaged in local culture. Intercultural communication is vital because tourism brings together people from different cultural backgrounds.

As noted by Dujmović and Vitasović (2022), social interaction plays a key role in shaping tourists' emotional responses and overall satisfaction. Misunderstandings may easily occur while expectations, behaviors have a different meaning. Developing skills such as cultural

understanding, active listening, and sensitivity to non-verbal signals helps individuals interact more effectively and respectfully during travel. These abilities support cultural exchange and reduce conflict. At the same time, digital technology has changed communication in tourism. According to Wahab (2017), information technology has improved, online platforms, mobile apps, and social media allow tourists to access information, communication with service providers.

Online platforms, mobile applications, and social media provide travelers with information, reviews, navigations, and communication with service providers. Technology makes trip planning easier, improves decision-making, and enhances safety, while also shaping how destinations present themselves to the world. Communication is central to modern tourism as it connects people across cultures, improves experiences, and creates more viable and welcoming travel environments. Effective communication, supported by social interactions, Intercultural communication and digital technologies, solutions to avoid issues are necessary to create meaningful and sustainable tourism experiences.

Effective communication

In the field of tourism, effective communication is essential for understanding unfamiliar cultural environments and interacting appropriately. Cross-cultural communication allows tourists to identify cultural differences in values, behavior, and social standards, which reduces misunderstandings during travel. According to Lukyanets (2020), global communication ability allows individuals to adapt their communication styles when interacting across cultures. This skill includes cultural understanding, empathy, and flexibility, which are especially important in international tourism. When travelers develop these skills, they are better prepared to engage respectfully, positively with host communities. Moreover, effective communication enhances emotional engagement and overall travel satisfaction. Tourism experiences are strongly influenced by human interaction than only physical attractions.

As noted by Dujmović (2022), communication through social interaction shapes tourists' emotional reaction and enhances their connection with local people. Clear and respectful communication helps tourists feel welcome and understood, and also allows the host to talk more openly about their culture. Without cross-cultural understanding, communication barriers can lead to confusion, discomfort, or negative experiences. Thus, intercultural communication is important for travelers because it supports mutual understanding, emotional connection, and positive relationships between the tourist and host.

Social and Intercultural Communication in Tourism

Social and intercultural communication plays a significant role tourist satisfaction and cultural experience. Social interaction between tourists and hosts allows visitors to engage directly with local culture, traditions, and everyday life. Tourism is not only about visiting destinations but also about interacting with people, traditions, and local ways of life. Vitasović (2022) explains that such interactions contribute to emotional connection and enhance the accuracy and confidence of tourism experiences.

When tourists communicate openly with local communities, they are more likely to feel involved and satisfied with their visit. Effective intercultural communication also requires specific skills to manage cultural differences. When tourists feel welcomed and understood through friendly interaction, they are more likely to develop positive appreciations of the destination and its culture. According to Albu (2015), cultural sensitivity, open-mindedness, and awareness of verbal and non-verbal communication are essential skills in tourism relations. Differences in communication styles, such as direct and indirect communication, may influence how thoughts

and information are explained. These differences can influence service meetings and social interaction between tourists and hosts. Hall's cultural concept suggests that people from different cultures rely on different levels of situation when communicating, which can affect understanding between tourists and hosts. When these cultural differences are not recognized, misunderstandings may occur. Therefore, combining social interaction with strong intercultural communication skills helps reduce conflict, improve service quality, and support respectful cultural exchange in tourism.

Information Technology in Tourism

Information technology plays an essential role in modern tourism by changing how communication, planning, and decision-making take place. Digital tools have altered the way tourists search for information, book services, and communicate. Wahab explains that information technology increases accessibility and efficiency in tourism by enabling faster communication and improved service delivery (Wahab, 2017). Online booking systems, mobile applications, and social media platforms help tourists to plan trips independently and make decisions based on real-time information. As Wahab claims, technology has become "a driving force behind the growth and competitiveness of the tourism industry" (Wahab, 2017).In addition, digital communication tools support interaction between tourists and service providers before, during, and after travel. This continuous communication improves customer satisfaction and trust. According to Buhalis and Gretzel, technology allows tourism organizations to personalize services and react more effectively to tourists' needs (as cited in Wahab, 2017). However, technology does not replace human interaction, instead it supports and enhances communication across cultures. Lukianets (2020) emphasizes that digital communication must be combined with intercultural competence to be effective in a global environment. Therefore, information technology is not only a technical tool but also a communication that connects people, cultures, and destinations in current tourism.

Challenges and Solutions in Tourism Communication

Despite the importance of communication in tourism, a myriad of challenges continue to affect interactions between tourists and host communities. Cultural differences, language barriers, and differing communication styles often lead to misunderstandings. Albu (2015) notes that miscommunication occurs when tourists and hosts explain behaviors and messages through their own cultural frameworks. Hall's theory of high-context and low-context cultures explains how meaning can be misunderstood when communication styles vary (Hall, as cited in Albu, 2015). Such misunderstandings may negatively influence tourist satisfaction and service quality.

Another challenge is the over-dependence on technology, which can reduce face-to-face interaction and cultural engagement. While digital tools improve efficiency, they may limit meaningful social interaction if it is not used appropriately. Dujmović and Vitasović (2022) argue that authentic social interaction remains essential for creating emotional connections between tourists and host communities. As they argue, "direct human contact enhances the depth of the tourism experience" (Dujmović & Vitasović, 2022).

To overcome these challenges, tourism professionals must develop intercultural communication skills and adapt communication strategies. Lukianets (2020) emphasizes the importance of training in intercultural skill, critical thinking, and digital communication. Combining cultural ability with technological innovation can reduce misunderstandings, improve service quality, and support sustainable tourism development. Effective communication strategies accomplish practical solutions to the challenges faced in global tourism today.

Conclusion

In conclusion, communication stands at the heart of modern tourism, influencing how travelers connect, interact, and make sense of the world. This article has illustrated that effective communication implanted in social interaction, intercultural ability and digital technologies is essential for creating meaningful, satisfying, tourism experiences. Social interaction allows tourists to engage with host communities, improving their cultural understanding and emotional connection to destinations. Intercultural communication skills, such as cultural awareness, adaptability, help reduce misunderstandings and support respectful exchanges in increasingly diverse environments. At the same time, information technology has altered the tourism industry by providing accessible, real-time information and enhancing decision-making processes. However, challenges remain, such as language barriers, cultural misinterpretations, and an overconfidence on technology that may limit interpersonal cooperation. To address these challenges, tourism professionals and travelers should enhance intercultural skills, apply digital tools carefully.

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THE ROLE OF MOBILE TECHNOLOGY IN DESTINATION MARKETING AND IMPACTS ON TRAVEL EXPERIENCE

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Abstract. *Smartphones have totally changed the way people travel. They are not only gadgets in pockets – they are travel partner tourists rely on before, during, and after the trip. This study explores how tourists use their gadgets at every stages of travel and what means for tourism industries trying to attract visitors. The COVID-19 pandemic advanced digital habits, so the research studies how mobile apps became the main way destinations talk directly to tourists. To get an understanding of what is happening, a survey was conducted from 110 Portuguese and looked at how people use destination apps. Here is what was noticeable: Smartphones stand right at the center of the modern travel experience. Tourists use them to obtain information instantly, wherever they are, which tourists can change their plan and get in touch with hotels or guides before travelling. For tourism businesses, well-designed apps are not just tools – they are powerful channels for sending personal messages that actually reach people. That is a big win for all participants. Apart from this, it is clear that mobile technologies are not just a nice-to-have, they are altering travel itself. All tourism industries that understand how to use this tools to contact directly and personally with travelers, are getting ready for the prosperity of the modern digital world.*

Keywords: *mobile technology, tourist experience, destination marketing, smartphone applications, consumer behavior, COVID-19.*

Introduction

In the 21st-century, smartphones become an essential and transformative part of tourism industries (Malmair et al., 2017). Mobile applications become an increasingly important tool in destination marketing in today's modern life. These destination applications serve as specific media platform which designed to communicate with visitors by influencing them with the unique sides of a destination. Technologies like mobile devices, interactive Web-connected kiosks, and many other digital connectivity systems allow this type of marketing. These technologies also will let destination marketers link real-life situations to virtual information and offerings which tourists can access whenever and wherever they want. In tourism industry, smartphones are used for directly communicating with visitors, deliver personalized messages through social media such as Instagram and Facebook, sharing real-time information and information about the problems which visitors can face during the visiting the place.

Law, et al (2009) states that mobile technologies make a convenient channel for tourists from which they can get information from anywhere they want, more importantly while at their destination. Smartphones became part of consumer life and they are integrated into even the most routine tasks of daily life. Smartphones made problems to tourists as difficulty to make decision due to much online information, tourists are really dependent on the phone in every part of their

trip. Tourists are mainly motivated to use their gadgets during the each stages of their trip; pre-consumption, consumption, and post-consumption. Core motivations are facilitating activities such as buying tickets, booking restaurants, hire guides; real time navigation (e.g. GPS, maps); easy access to information and destination image (e.g. opening hours, reviews). Socially, tourists use smartphone for sharing experience via social media. Psychologically, key motivations are efficiency and convenience to plan the trip.Digital transformation of tourism industry is based on the smartphone's becoming into a necessary travel tool, which significantly changes tourist behavior. The main motivations to use gadgets are easy access to real-time information, maintain contact with families and friends, and increase security level.

Mobile technologies as essential tool in tourism industry

Tourism industries are reshaped into digital tourism as mobile technologies became an essential tool for marketers by serving as the platform in which they can directly contact with consumers and provide online sites to book trips and meeting traveler's needs. According to Mobile Travel Trends 2019, 61% of the travelers "usually" or "sometimes" use apps for booking flights, and 62% of travelers agree that this option is very essential. Hsu & Lin (2015) and Tan (2017) noted that travel apps were quickly used as a travel tool and in tourism information research and travel planning. These mobile apps very similar with personal computers and it is possible to update and customize gadgets to meet personal needs (Rakestraw et al., 2013). Tourism industries are using mobile apps to attract consumers by advertising their business and sharing real time view of the destination.

Moreover, during the COVID-19 pandemic tourism businesses made profit from mobile technologies by directly contacting with travelers, answering for their questions from anywhere and giving them some advice what to do while they are on their trip without meeting each other which was strictly forbidden. According to Gössling, for the tourism industries Information and Communication Technologies (ICT) development is separated into four stages, in which every stage covers one decade (2021): (1) Opportunity (1985-1995): it is about the important achievements such as company website, global distribution systems, and digitalized reservation systems; (2) Disruption (1996-2006): it is about the platforms economy; (3) Immersion (2007-2015): notes the large integration of ICT in consumer's lives; (4) Usurpation (2016-ongoing): describes personalized deals, guided by big data insights. Fernandez-Cavia et al. noted that following these steps mobile technology made so disadvantages also as poor internet connection in some locations, limited screen size of the gadgets and low vision level of smartphones (2017).

Mobile applications are changing tourist behavior

Smartphones are having great role in changing the tourists' behavior by motivating them with such convenience as socializing with professionals, changing their plan at the last minute, easy booking, and having real time information. In 2012, Kennedy-Elden & Gretzel noted that in the next year, by the growing usage of the smartphones and mobile apps, this market succeeds greatly in the history of consumer technology. Tourist are becoming really dependent on their phone as they mentioned in the questionnaire smartphones are their travel partner and helping them in many ways to solve their needs such as navigating certain location, finding exact or pocket friendly hotels and restaurants, make decisions, money transactions. According to Wang et al., survey results of 110 Portuguese tourists showed that 60% of them reported that Mobile Technology Apps altered their travel experience by improving some spheres as planning and booking (2014). Following this advantages tourists also faced some disadvantages especially in decision making process because of abundant choices on internet.

This become more complex, tourists are sharing their experience through feedbacks in travel platforms, making blogs in social media as Instagram and Facebook. Smartphone are becoming part of all human life, both professionally and personally, from even the most routine task as shopping and making food or even daily commuting. Oh et al. (2009) reported that mobile technology let excellent flexibility for both industries and tourists over the accessibility of the informational channel. tourists are relying heavily on their phones and they are busy by taking photos and sharing them on social media instead of enjoying the reality beyond the phone. To prevent this kind of problems tourism educators should encourage tourist to use smartphones in balanced way.

Main motivations to use Mobile Technologies in the trip. Tourists are greatly motivated to use their gadgets while they are travelling. The primary motivations are the speed, convenience and access to any kind of services from anywhere and anytime. In 2010, Höpken et al. noted that the main motivation is that gadgets are supporting tourists on their trip and at their destination. Different authors find out similar motivations. Okazaki et al. (2015) noted that smartphones are motivating consumers to use them by providing better speed and access to information, finding interesting activities, accommodations, and restaurants; seeking feedbacks and taking fast actions as they need real-time information. Wang et al. (2014) found about 12 motivations, that social interaction, fun, contact with family or friends, staying safe during the trip. Smartphones also let tourists to easily access to the information which can affect ton their trip: information about the weather, attraction, and transportation (No & Kim, 2014). Buhalisand Costa (2006) divided the motivations in three stages of tourism consumption: pre-consumption, consumption, and post-consumption. In pre-consumption stage tourists want to plan, make their expectations, make decisions, pay for their booked tickets, and make their expectations. In the consumption stage, the most important for tourists is to be connected, during these stage tourists navigate the certain locations as they are in unfamiliar country, making decisions quickly (e.g., finding a restaurant). Finally, in post-consumption stage, which is right after the trip, tourists use their smartphones to share their photos which was token during trip, give advices for the new visitors of that destination what to do and what kind of challenges they would be faced with, and relive the trip again. “The feeling of security is essential for smartphone and MTA users and several other needs and desires from the way they experience travel” (Dias & Afonso, 2021).

Conclusion. The research examined several roles of mobile applications in destination marketing and its influence on the new tourists’ experience. It is clear that smartphones are turned from just communication tools into irreplaceable travel agent. The result of the survey shows that mobile technology has motivated tourists to use them in all phase of traveling – pre-consumption, consumption, and post-consumption by providing easy access to the information, real-time navigation, booking flights and accommodation and even to hire guides, and acting as the platform in which tourists share recommendations and feedbacks about the experienced trip. Smartphones have become the newest phenomenon in the tourism industry. For destinations, functionalized apps act as a powerful platform to contact directly with the consumers to answer to their questions.

The adopting process of mobile apps by destination marketers was boosted during the COVID-19 pandemic by maintaining the importance of the connection between destinations and visitors. In contrast, tourists are facing many challenges, including overloaded information, over-using of the smartphones that makes problem with decision making process and reducing authentic experience. To avoid such kind of problems, tourism providers should teach consumers mindful use of smartphones while traveling (Huang, 2017), as well as government and tourism boards

should cooperate with developers of apps to update the data which they have already (Koo et al., 2016).

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FOREIGN SCIENTIFIC APPROACHES AND BEST PRACTICES IN ENSURING THE SUSTAINABILITY OF FAMILY ENTERPRISES IN THE SERVICE SECTOR

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Abstract*. This article analyzes foreign scientific approaches and best practices in ensuring the sustainability of family enterprises operating in the service sector. It examines management models applied in the United States and European countries, the role of professional management, succession planning, and innovative technologies in achieving sustainable development. The research results contribute to the development of scientific and practical recommendations aimed at adapting foreign experience to national conditions and improving the performance of family enterprises.*

Keywords*: family enterprises, service sector, economic sustainability, foreign experience, management models, professional management, succession, innovations.*

Introduction: In global economic practice, family enterprises operating in the service sector are regarded as an important supporting institution for the stable functioning of the economic system. In most international studies, the concept of "sustainability" of family business is not limited solely to financial profitability, but is explained in a comprehensive manner through such factors as maintaining intergenerational continuity, preserving corporate values, and fulfilling social responsibility. In this sense, the family entrepreneurship model is increasingly substantiated in academic circles as performing the function of the "backbone of the economy." At the global level, the fact that family enterprises generate more than 70 percent of gross domestic product indicates that they represent not only micro-level business entities but also a strategic systemic element influencing macroeconomic stability.

This general trend is particularly evident in the service sector, since factors such as direct interaction with customers, trust, reputation, and service quality become the main determinants of sustainability. Therefore, in analyzing foreign experience in ensuring the sustainability of family enterprises in the service sector, the U.S. model has special methodological and practical significance. Representatives of the American academic school, in particular J. Chrisman and J. Chua, explain the long-term viability of family businesses through the concepts of "professionalization" (professional management) and "strategic flexibility." That is, the introduction of modern corporate governance standards while preserving family values is considered a mechanism that protects family enterprises from internal conflicts and enhances their adaptability to market conditions.

In U.S. practice, especially in large service companies with family business origins (such as Walmart and Marriott), the institutionalization of family values occupies a central place as one of the key conditions for ensuring sustainability. In the American experience, the long-term mechanism of sustainability is achieved through the integration of family values with corporate governance standards. Along with the business plan, the presence of a "Family Constitution" is

interpreted as an important strategic instrument of family business management. This document normatively regulates the roles of family members in the business, management authority, profit distribution, and succession issues, and serves to minimize agency problems and internal conflicts that are highly likely to arise within the enterprise. As a result, a balanced harmony between family and business interests is formed, which acts as an institutional foundation strengthening the long-term economic sustainability of the enterprise.

European scientific approaches, particularly the experience of Germany and Switzerland, explain the sustainability of family businesses through reliance on different institutional mechanisms. The conceptual basis of this model is the "Mittelstand" (medium-sized business) paradigm, which has been formed as an important platform guaranteeing the long-term viability of medium-sized enterprises, including family businesses, within the economic system. In the German model, family enterprises are considered global leaders in terms of longevity. German scholars explain this, on the one hand, by the priority of the "niche leadership" strategy, and on the other hand, by the development of mechanisms for training qualified personnel in accordance with enterprise needs through the dual education system. In particular, German family enterprises operating in service industries (logistics, hospitality, and high-technology services) maintain stable cooperative relationships with customers for 30–40 years, which serves as a key factor in forming a mechanism of "reputational sustainability" in the service sector.

Literature Review: Family enterprises play a significant role in the global economy as a stable segment of the economic system. Research shows that family businesses contribute substantially to the development of the small and medium-sized enterprise sector, the creation of new jobs, and the enhancement of regional economic potential. At the same time, they ensure long-term sustainability through corporate governance, continuity of ownership, and intergenerational succession in management. An analysis of the role of family enterprises in maintaining long-term competitiveness highlights their ability to increase economic efficiency through internal values and social responsibility. The review of scientific sources indicates that family enterprises are not only generators of income within the economic system, but also key actors in promoting sustainable development and economic diversification. Therefore, the study of their management principles, succession processes, and mechanisms for improving economic performance enhances the relevance and significance of this research.

Research Methodology:

This study analyzes foreign scientific approaches and best practices in ensuring the sustainability of family enterprises operating in the service sector. The research employs a systematic approach, comparative analysis, and inductive and deductive methods. Based on foreign academic literature (the experience of the United States, Europe, and Asian countries), the key factors affecting the sustainability of family enterprises are identified, and their similarities and differences are compared. In addition, international statistical data and the Family Business Index are used to formulate general conclusions. This methodological approach serves to systematize foreign experience and develop scientific and practical recommendations for adapting it to national conditions.

Analysis and Discussion of Results

At the same time, in international academic literature, the practice of using integrated indicators such as the *Family Business Index* has become widespread in the comprehensive assessment of the sustainability of family enterprises. This index makes it possible to evaluate a firm's economic performance (income), the share of family members in management, and the

company's social impact within a unified framework. In this context, sustainability is measured not only by financial indicators, but also by the institutional strength of family participation in governance and the capacity to create social value. For example, in the Finnish experience, family enterprises are reported to account for about 80 percent of the national economy, and the establishment of a specialized *Family Business Association* that provides institutional support and advisory mechanisms to ensure their sustainable development is highlighted as an important best practice.

The specific characteristics of the service sector—namely the intangibility of services, direct interaction with customers, and the prominent role of reputation and trust capital—require broader conceptual approaches to assessing the sustainability of family enterprises compared to traditional manufacturing firms. Therefore, foreign academic literature has developed various regional models to explain family business sustainability, which differ in terms of institutional norms, management culture, and market mechanisms. In particular, the U.S. and European (Germany–Switzerland) schools interpret the sustainability of family service enterprises based on different determinants. When these approaches are generalized, they can be represented through the following conceptual model:

USA Model	**Europe (Germany) Model**
Professional management	Mittelstand (long-term orientation)
Family Constitution	Dual education and workforce training
Access to capital markets	Niche leadership

Figure 1.3.1. Conceptual Models of Sustainability of Family Service Enterprises in the U.S. and European (Germany–Switzerland) Approaches

This conceptual framework shows that in the U.S. model, sustainability is strengthened through such institutions as professional management, the family constitution, and access to capital markets, whereas in the German (European) model this process is ensured through the philosophy of *Mittelstand*, the dual education system, and the strategy of niche leadership. Thus, both approaches lead to the same overall outcome—economic sustainability and longevity—however, the mechanisms through which this result is achieved differ.

At the same time, in Asian countries the sustainability of family enterprises is more closely associated with management culture and succession institutions. In particular, the experience of South Korea (the chaebol system) and Japan demonstrates that paternalistic management and intergenerational succession culture serve as important pillars of sustainability in family businesses. In Japanese practice, the concept of *Shinise* (centuries-old family-owned shops, hotels, and service enterprises) illustrates that sustainability can be achieved by integrating innovation with traditional values while preserving long-established brands. The experience of South Korea's *SK Group* further confirms in practice that maintaining family control while pursuing global diversification helps reduce market risks and ensure stable growth.

International experience indicates that, in order to scientifically compare these models, a unified system of indicators is required. For this purpose, the key mechanisms used to assess the sustainability of family enterprises in the service sector and their measurement indicators are summarized in Table 1.3.1.

*Indicators of Family Enterprise Sustainability in International Practice**

Country / Region	**Country / Region**	**Country / Region**
USA	Professionalization	Market capitalization and profit

Germany	Clustering (Mittelstand)	Export potential and longevity
Japan	Tradition (Shinise)	Brand history and customer loyalty
South Korea	Diversification	Asset turnover and technology

*** Source: Systematized by the author based on the studies of Toshpo‘latov (2022) and Jurayev (2024).**

Another approach explaining the international sustainability mechanisms of family enterprises in the service sector is the theory of **Social Capital**. Within this approach (in particular, among followers of P. Bourdieu’s academic school), the sustainability of family businesses is assessed through the quality of their relationships with society, institutional trust, standards of integrity, and the level of social legitimacy. Especially in the context of Muslim countries, the implementation of the principles of **Halal tourism** and **Islamic finance** in service enterprises is identified as a practical mechanism that strengthens sustainability.

Conclusions and Recommendations: Based on the analysis of foreign models of sustainability of family businesses in the service sector, the following general scientific conclusions have been formulated:

- **Institutional integration:** Sustainability is not determined solely by a firm’s internal resources; it also directly depends on the stability of the institutional “ecostructure” formed by the state, professional associations, and supporting infrastructure.
- **Priority of professional management:** Foreign practice shows that adapting management to professional governance standards while preserving family values increases the longevity of service enterprises.
- **Socio-emotional balance:** Successful international models rely on transforming family values (SEW) into an economic asset and integrating them with competitive service strategies (Suddaby R., Jaskiewicz P., 2020).
- **Determinant role of digital transformation:** In the service sector, digitalization (CRM/ERP systems, cloud technologies, and the platform economy) functions not only as a tool for increasing revenues, but also as a mechanism for risk management and resilience to market shocks.
- **Scientific approach to succession:** Succession is not merely a process of transferring ownership, but a management technology that requires the renewal of intellectual capital, preservation of corporate values continuity, and continuation of technological modernization.
- **Effect of clustering and cooperation:** A cluster environment optimizes marketing and logistics costs, standardizes service quality, and provides small family service enterprises with economic “scale” advantages to compete with large rivals.
- **Resource efficiency and “green” advantage:** Relying on energy efficiency and renewable energy technologies not only reduces costs for family service enterprises but also strengthens their reputational sustainability.

As a final conclusion, it should be emphasized that foreign scientific approaches to ensuring the sustainability of family enterprises in the service sector constitute an important methodological foundation for the economy of Uzbekistan. The professional management mechanisms of the United States, the cluster-based model of Germany, and the succession culture–oriented approaches of Asian countries, when integrated with national institutions—particularly

strong family ties and the mahalla system—can become innovative drivers for increasing the share of the service sector in GDP and strengthening public welfare.

The theoretical conclusions formulated in this section create a conceptual basis for subsequent chapters, which will focus on econometric analysis of family enterprise performance, quantitative assessment of sustainability determinants, and the development of practical development models.

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