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MAIN DIRECTIONS OF DIGITALIZATION OF PHARMACEUTICAL PRODUCTION

Gaynazarov Sultan Mamanazarovich
Mirzo Ulugbek National University of Uzbekistan,
Department of Artificial Intelligence Candidate of
Physical and Mathematical Sciences, Associate Professor
Ne'matillayev Farruhjon Umidjon ugli
Master's student at the National University of
Uzbekistan named after Mirzo Ulugbek

Abstract. This paper examines the processes of digital transformation in the pharmaceutical industry, as well as the role and significance of modern information and communication technologies such as artificial intelligence, blockchain, the Internet of Things (IoT), RFID, and others in production and supply chain management. The study analyzes the effectiveness of using digital technologies in drug development, manufacturing, storage, and distribution processes. It also explores the potential of blockchain and IoT technologies in quality control of pharmaceutical products, combating counterfeiting, and optimizing logistics systems. Furthermore, the paper substantiates the prospects of digitalization in the pharmaceutical industry of Uzbekistan and highlights the importance of implementing modern technologies.

Keywords: pharmaceutical industry, digital transformation, artificial intelligence, blockchain, Internet of Things (IoT), RFID, logistics, supply chain, medicines, automation, digital technologies.

Current that day digital technology (RT) world economy height And technological development basic from factors one be a service The implementation of digital technologies contributes to increased competitiveness, the creation of new business opportunities, and the acceleration of innovative development in various sectors of production, including the economy of Uzbekistan . The digital economy expands opportunities for developing new business models, attracting investment, finding qualified personnel, expanding cooperation, and entering domestic and foreign markets. At the same time, digital technologies play a vital role in employee training, knowledge sharing, and the implementation of innovative ideas.

Digitalization is the process of widespread adoption of modern digital technologies across all spheres of society. It serves to improve practical efficiency by integrating information and communications technologies into the economy, healthcare, education, and other sectors. The core essence of digitalization lies in making accurate and effective decisions through process automation, data transfer to the digital environment, and rapid analysis. Ensuring the flexibility and efficiency of this process is one of the key objectives of digitalization.

Uzbekistan's pharmaceutical industry is also a sector of significant social importance and has been rapidly developing in recent years. Meeting the population's needs for high-quality medicines, producing import-substituting products, and increasing export potential are among the sector's priorities. Therefore, digitalization of the pharmaceutical industry is one of the most pressing challenges of our time.

The digital transformation of the pharmaceutical industry in our country, automation of production processes, enhanced quality control, and efficient supply chain management are of

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paramount importance. This not only improves product quality but also strengthens the industry's competitiveness in the international market.

The project aims to develop proposals based on the study of advanced foreign experience and its adaptation to national conditions, as well as methods for the formation and development of a digital business environment for Uzbek pharmaceutical enterprises.

The theoretical basis for studying the characteristics of digital transformation in manufacturing is the work of international and domestic scholars. In particular, the work of international researchers such as K. Schwab, D. Rifkin, J. Schumpeter, R. Baldwin, D. Bell, R. Buchta, and R. Hicks, as well as scholars from Uzbekistan and the CIS countries, is of great significance in this area. Research on industrial development in the context of the digital economy, the integration of modern technologies into production processes, and the improvement of management mechanisms deserves special attention.

Over the past decade, the pharmaceutical industry has experienced a shift from traditional manufacturing to biotechnology and accelerated digitalization. This has further increased scientific interest in this field. Current research emphasizes the role of innovation, investment, and digital technologies in the development of the pharmaceutical industry.

Based on an analysis of scientific sources, three main areas of digital transformation in pharmaceutical production can be identified:

- creation of new drugs;
- direct processes of production;
- Support areas: raw material accounting, accounting, marketing, product labeling and delivery systems.

Key technological tools for digital transformation include blockchain, cloud services, big data, the Internet of Things (IoT), machine learning, mobile applications, augmented reality (AR), virtual reality (VR), and digital twins.

The introduction of digital technologies into Uzbekistan's pharmaceutical industry is also proceeding gradually. Specifically, special attention is being paid to the implementation of modern accounting systems at enterprises, automation of production processes, the use of cloud technologies, and the improvement of logistics systems. Many companies are seeking to improve efficiency through the implementation of digital management systems.

At the same time, advanced technologies such as big data, artificial intelligence, and business process automation have not yet achieved widespread adoption, but there are plans for their future application. Predictive analytics, smart manufacturing, and blockchain technologies are also considered promising areas.

Experts are paying close attention to supply chain control, particularly in the pharmaceutical industry. In this context, intelligent logistics systems based on the Internet of Things (IoT) are seen as a key solution. Furthermore, artificial intelligence and machine learning technologies offer significant opportunities for identifying compounds with biologically active substances and creating new medicinal molecules.

The digital transformation of the Uzbek pharmaceutical industry will not only increase production efficiency but also become a key factor in improving product quality, reducing costs, and ensuring competitiveness in the international market.

Table 1. Results of using digital solutions.

Results of using digital solutions	**Implemented or in the process of implementation, %**	**Planned implementation, %**

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Results of using digital solutions	**Implemented or in the process of implementation, %**	**Planned implementation, %**
Accounting systems (CRM, SAP, etc.)	50	21
Cloud technologies	38	25
Full automation of individual business processes	25	38
Big data and machine learning	6	21
Robotic automation of business processes	6	19
Predictive analytics	4	12
Blockchain (distributed encrypted database)	4	4
Intelligent manufacturing	4	4
Video analytics and machine vision	2	4

Note: These indicators reflect the approximate state of digital technology implementation in Uzbekistan's pharmaceutical industry. As the table shows, the most widely used technologies are accounting systems and cloud solutions. While advanced technologies (artificial intelligence, big data, and robotics) are not yet fully developed, there is growing interest in their future implementation.

It should be noted that the most promising digital solutions that not only simplify business operations but also take pharmaceutical production to a new technological level include the search for new biologically active compounds using artificial intelligence (AI), data transfer and product labeling using blockchain technology, and the use of Internet of Things (IoT) systems to analyze and control all stages of production.

When developing new drugs, large pharmaceutical companies use AI-based algorithms to predict the likely properties of new compounds. AI provides a significant advantage during the initial screening of molecules. Neural networks can analyze massive amounts of data and identify molecules with the greatest potential. They also help identify potential drug side effects. For example, if many patients report similar symptoms when taking a certain drug, AI can identify this connection and warn of potential risks. AI also makes it possible to model drug interactions with biological systems.

As a practical example, the GENTRL system, based on neural networks, was used to create drugs that block the activity of the DDR1 protein. The DDR1 enzyme may be involved in fibrosis, so reducing its activity is being considered as a treatment option. The GENTRL system generated these inhibitors in just 21 days, while the entire modeling, synthesis, and validation process took 46 days. The cost was approximately $150,000. By comparison, creating a similar drug using traditional methods would cost large companies millions of dollars and take several years.

Artificial intelligence is also widely used in the development of new antibiotics. One of the pressing problems in modern medicine is bacterial resistance to antibiotics. This problem often arises from improper use of medications and failure to follow doctor's recommendations. One

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way to address this problem is by modifying existing antibiotics, but this process is very complex and time-consuming. Artificial intelligence significantly accelerates this process.

For example, the VarQuest algorithm identified thousands of peptide groups in a very short time, compared to over a century of research using traditional methods. This opens up new opportunities for biologists and helps predict emerging trends in microbiology.

It also plays a significant role in developing drugs for diseases previously considered difficult to treat, including Parkinson's and Alzheimer's. Previously, pharmaceutical companies showed little interest in working with rare diseases, as this area was considered economically unviable. However, advances in artificial intelligence technologies have reduced the cost of drug development by 25-30%, and interest in these areas is growing.

Another important area of IT application in the pharmaceutical industry is product labeling. According to the World Health Organization, approximately 10 percent of drugs worldwide and over 30 percent in developing countries are counterfeit. This problem is often linked to underdeveloped mechanisms for verifying drug authenticity.

This issue is also relevant for Uzbekistan, and using blockchain technology to address it offers significant opportunities. This technology makes it possible to track the movement of medications from manufacturer to consumer, verify their authenticity, and prevent counterfeit products.

A blockchain is a systematically organized chain of information in which each subsequent block contains all the information created in previous blocks. Unauthorized access attempts to this system are automatically rejected because such information does not correspond to the "information field" of the previous block. These features significantly enhance information security. Today, the capabilities of blockchain technology are actively used by leading pharmaceutical companies, particularly as an important tool for preventing the production and distribution of counterfeit products.

Blockchain-based digital systems enable complete control of the supply chain, tracking the movement of every drug from the manufacturer to the end consumer. For example, applications like BlockRX operate on a "digital ledger" and store all information related to the production of legitimate pharmaceuticals. This system automatically detects and rejects counterfeit products. In practice, illegal interference with such a system is virtually impossible. The system automatically controls raw materials and supplies, records order volumes, tracks their receipt and use, and monitors the movement of each manufactured drug from the manufacturer to the distributor and from there to the retailer.

The Industrial Internet of Things (IIoT) connects all elements involved in the production process—equipment, people, machines, and databases—into a single network. Data is collected and transmitted using specialized sensors and software, enabling automated process control and monitoring.

In manufacturing, the Industrial Internet of Things (IIoT) plays a vital role in monitoring equipment conditions. For example, sensors collect parameters such as temperature, vibration, and error codes. This data can be used to determine equipment efficiency and assess whether production capacity is being fully utilized.

Preventive maintenance. Sensors continuously analyze equipment condition and identify malfunctions before they become serious problems. This extends the equipment's lifespan and creates a safer working environment for employees.

Furthermore, the Internet of Things technology can be used to create modern logistics systems for supply chain management in the pharmaceutical industry.

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Pharmaceuticals are temperature-sensitive products that require specific temperature and humidity conditions during transportation and storage. According to the World Health Organization, approximately 25 percent of vaccines reach consumers in an unusable condition due to failure to maintain proper temperature control. A failure at any stage of the supply chain can undermine the effectiveness of the entire process.

Thus, the concept of the "cold chain" was developed in the healthcare system, encompassing a set of measures aimed at ensuring the required temperature at all stages of pharmaceutical production, from manufacturing to delivery to the consumer. Maintaining a stable temperature during transportation is particularly important. Failure to maintain the correct temperature can reduce the effectiveness of medications and even harm human health.

Modern traditional monitoring systems don't allow for real-time temperature monitoring, meaning data is only collected after the product reaches its destination. This limits rapid response capabilities and is a significant drawback. Furthermore, since pharmaceutical products are expensive, spoilage can lead to significant economic losses.

To address this issue, the introduction of Internet of Things (IoT) technologies into Uzbekistan's pharmaceutical industry is also of paramount importance. IoT is a global network connecting physical and virtual objects via the internet, collecting real-time data using sensors. For example, sensors installed in vehicles continuously monitor temperature, humidity, and other parameters of medications, and this data is transmitted to the logistics system's control center. This makes the supply chain more efficient, safe, and reliable.

Radio-frequency identification (RFID) and wireless sensor devices are key drivers of the Internet of Things (IoT) in supply chains. RFID tags can be equipped with various sensors (e.g., thermometers) and additional devices. This allows them to be connected to a network and monitor environmental parameters (temperature, humidity, etc.), as well as obtain location information. These innovative tags carry a unique identification number or IP address and are attached to pharmaceutical products during transportation.

The IoT architecture typically consists of three main layers:

1. level of perception (information collection),
2. network layer,
3. level of service.

The information collection stage is the most important stage in the IoT system, where all the necessary information is collected from physical devices using sensors, RFID tags and other devices.

At the network layer, collected data is transmitted. Wireless sensor networks (WSNs), mobile communication systems, and other communication technologies are used for this purpose. This layer ensures a stable and reliable network infrastructure.

By implementing this intelligent management system, it's possible to create an effective monitoring system for the pharmaceutical and medical supply chain at a relatively low cost. This system will enable logistics companies to identify any disruptions in storage and transportation processes in real time and take prompt action.

Today, information technology occupies a key place in the pharmaceutical industry and is rapidly developing. Specifically, it plays a significant role in data exchange, drug barcoding, management accounting, statistical analysis, the creation of modern web platforms, and supporting healthcare initiatives.

In Uzbekistan, the pharmaceutical industry is considered a key area of innovative development within the framework of strategies for developing the information society and

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transitioning to a digital economy. Therefore, digitalization processes must be actively implemented at all stages of production.

and efficient information processing, optimizes the production process and enables the automation of repetitive and simple processes. Artificial intelligence-based algorithms significantly accelerate the development of new drugs, blockchain technology ensures reliable product labeling, and the Internet of Things (IIoT) enables real-time management of all production processes.

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