

**THE ROLE OF ARTIFICIAL INTELLIGENCE AND DIGITAL TRACK-AND-TRACE
SYSTEMS IN STRENGTHENING THE SAFETY OF PHARMACEUTICAL
CIRCULATION IN AZERBAIJAN****Said Y. Farzullayev*, Mahbuba N. Valiyeva, Murad Y. Suleymanov**Department of Pharmaceutical Technology and Management, Azerbaijan Medical University, Baku, Azerbaijan.
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Public Legal Entity "Analytical Expertise Center" of the Ministry of Health, Baku, Azerbaijan.**DOI:** <https://doi.org/10.5281/zenodo.19507995>**How to cite this Article:** Said Y. Farzullayev*, Mahbuba N. Valiyeva, Murad Y. Suleymanov. (2026). The Role of Artificial Intelligence And Digital Track-And-Trace Systems In Strengthening The Safety of Pharmaceutical Circulation In Azerbaijan. European Journal of Pharmaceutical and Medical Research, 13(4), 404–409

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ABSTRACT

Ensuring the safe and transparent circulation of pharmaceutical products is a critical priority for healthcare systems and regulatory authorities. Increasing globalization of pharmaceutical supply chains and the growing complexity of medicine distribution have intensified challenges related to counterfeit medicines, unauthorized distribution channels, and limited traceability of pharmaceutical products. These issues highlight the need for advanced digital solutions capable of improving supply chain transparency and strengthening regulatory oversight. Artificial intelligence (AI) and pharmaceutical track-and-trace systems have emerged as promising technologies for monitoring medicine circulation and enhancing supply chain security. This study examines the role of artificial intelligence and digital track-and-trace systems in strengthening the safety of pharmaceutical circulation in Azerbaijan. A narrative review methodology was used to analyze international scientific literature, regulatory frameworks, and existing pharmaceutical traceability systems implemented in different countries. The findings indicate that track-and-trace systems based on serialization technologies enable regulators to monitor the movement of medicines across supply chains and verify product authenticity. Artificial intelligence technologies can further enhance these systems by analyzing large volumes of distribution data, detecting irregular supply chain activities, and identifying potential circulation risks. Integrating AI with national track-and-trace systems could significantly improve transparency, strengthen regulatory control of pharmaceutical distribution, and support the digital transformation of pharmaceutical regulation in Azerbaijan.

KEYWORDS: Artificial Intelligence; Pharmaceutical Circulation; Track-and-Trace Systems; Pharmaceutical Supply Chain; Digital Health; Medicine Traceability; Azerbaijan.**INTRODUCTION**

Ensuring the safe circulation of pharmaceutical products is an essential responsibility of national healthcare systems and regulatory authorities. Pharmaceutical circulation encompasses the processes involved in the manufacturing, distribution, storage, transportation, and dispensing of medicines within healthcare systems. Effective monitoring of these processes is necessary to ensure that medicines reach patients safely and through authorized supply channels.

The globalization of pharmaceutical markets and the expansion of international trade have significantly increased the complexity of pharmaceutical supply chains. Medicines often pass-through multiple intermediaries before reaching end users, including manufacturers, distributors, wholesalers, pharmacies, and healthcare institutions. This complexity increases the risk of counterfeit medicines, unauthorized distribution networks, and limited transparency in medicine circulation.

Counterfeit and falsified medicines represent a significant global public health challenge. According to international reports, falsified or substandard medical products may account for a considerable proportion of pharmaceutical circulation in some regions. These products not only threaten patient safety but also undermine trust in healthcare systems.

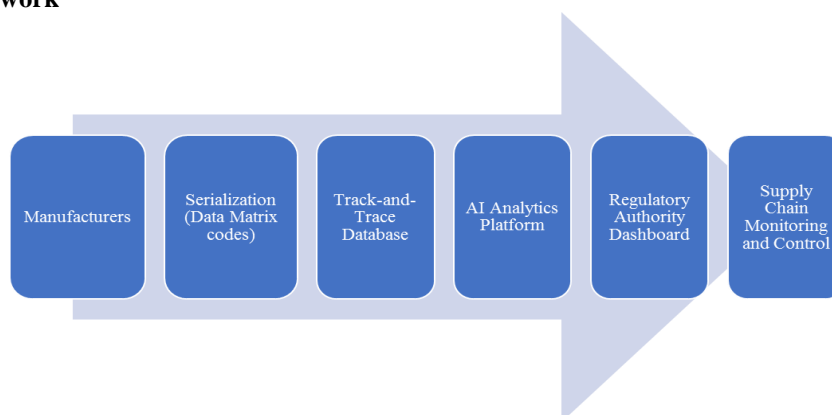
Traditional regulatory mechanisms for monitoring pharmaceutical circulation often rely on manual documentation, inspections, and paper-based reporting systems. These approaches may limit regulators' ability to monitor supply chains in real time and detect irregularities in medicine distribution.

In recent years, digital technologies have emerged as effective tools for improving supply chain transparency and regulatory oversight. Track-and-trace systems allow

regulators to monitor the movement of pharmaceutical products across supply chains through serialization and digital identification technologies. Artificial intelligence technologies can further enhance these systems by enabling advanced data analysis and anomaly detection in pharmaceutical distribution networks.

Azerbaijan has taken important steps toward modernizing pharmaceutical regulation and improving transparency in medicine circulation. Implementing advanced digital technologies such as AI and track-and-trace systems may significantly strengthen regulatory capacity and improve monitoring of pharmaceutical distribution. This study examines the role of artificial intelligence and digital track-and-trace systems in strengthening the safety of pharmaceutical circulation in Azerbaijan.

Conceptual Framework



AI analyzes supply chain data in real time to detect anomalies and support regulatory decision-making.

Figure 1: Conceptual Framework for AI-Supported Pharmaceutical Circulation Monitoring.

MATERIALS AND METHODS

This study employed a narrative review methodology to analyze scientific literature and regulatory frameworks related to pharmaceutical circulation monitoring, digital traceability systems, and artificial intelligence applications in supply chain management.

Relevant literature was identified through academic databases, international regulatory reports, and policy documents published by organizations such as the World Health Organization, the European Medicines Agency, the Organisation for Economic Co-operation and Development, and the U.S. Food and Drug Administration. The search focused on publications related to pharmaceutical track-and-trace systems, serialization technologies, supply chain security, and artificial intelligence applications in healthcare and logistics.

The analysis included international case studies of track-and-trace systems implemented in different countries, including regulatory frameworks such as the European Union Falsified Medicines Directive and the United States Drug Supply Chain Security Act. These systems

were examined to identify key components, operational mechanisms, and potential benefits for strengthening pharmaceutical circulation monitoring.

The findings were then assessed in relation to the pharmaceutical regulatory environment in Azerbaijan to evaluate potential opportunities for integrating artificial intelligence and track-and-trace technologies into national pharmaceutical monitoring systems.

RESULTS AND DISCUSSION

Global trends in pharmaceutical circulation monitoring

The safe circulation of pharmaceutical products has become a central concern for regulators due to the increasing complexity and globalization of pharmaceutical supply chains. Modern pharmaceutical distribution networks involve numerous actors, including manufacturers, importers, distributors, wholesalers, pharmacies, and healthcare institutions. Medicines frequently cross-national borders and move through several logistical stages before reaching patients. This complexity increases the risk of counterfeit medicines entering the supply chain and makes it more difficult for regulators to monitor product movement effectively.

International reports indicate that counterfeit and falsified medicines represent a persistent global challenge. These products may contain incorrect ingredients, insufficient active substances, or harmful contaminants, posing significant risks to public health and undermining trust in healthcare systems. In response to these risks, many countries have introduced regulatory measures aimed at improving traceability and transparency in pharmaceutical distribution networks.

One of the most important regulatory developments in recent years has been the adoption of pharmaceutical traceability systems. These systems enable regulators to track the movement of medicines throughout the supply chain and verify product authenticity. By providing visibility into supply chain activities, traceability systems help prevent counterfeit medicines, detect unauthorized distribution, and improve the ability of regulators to respond to potential supply chain disruptions.

Several countries and regions have implemented national or regional pharmaceutical traceability frameworks. For example, the European Union introduced the Falsified Medicines Directive (FMD), which requires prescription medicines to include unique identifiers and tamper-evident packaging. Pharmacies and wholesalers must verify these identifiers before dispensing medicines to patients. Similarly, the United States implemented the Drug Supply Chain Security Act (DSCSA), which establishes a nationwide electronic system for tracing pharmaceutical products at the package level.

Türkiye has implemented one of the most comprehensive pharmaceutical track-and-trace systems in the world through its Pharmaceutical Track and Trace System (ITS). This system enables real-time monitoring of pharmaceutical distribution and provides regulators with detailed information on the movement of medicines across the supply chain. These international experiences demonstrate the growing importance of digital technologies in strengthening pharmaceutical circulation safety.

The implementation of such systems highlights the need for integrated digital infrastructure capable of managing large volumes of supply chain data. As pharmaceutical traceability systems generate extensive datasets related to product movement, advanced analytical tools are required to process and interpret this information effectively. Artificial intelligence technologies have emerged as a promising solution for addressing this challenge.

Track-and-trace systems and serialization technologies

Track-and-trace systems rely on serialization technologies that assign a unique identifier to each medicine package. Serialization typically involves the application of machine-readable codes, such as GS1 DataMatrix barcodes, which contain key product information. This information usually includes the

product code, serial number, batch number, and expiration date.

Once serialized, each medicine package can be tracked as it moves through the supply chain. Transactions involving the product—such as manufacturing, distribution, wholesale transactions, and pharmacy dispensing—are recorded within centralized databases. These records provide regulators with a digital trail that documents the movement of each pharmaceutical product.

The implementation of serialization technologies offers several benefits for pharmaceutical circulation monitoring. First, serialization improves transparency in supply chains by enabling regulators to trace the origin and movement of medicines. This capability makes it more difficult for counterfeit products to enter legitimate distribution networks.

Second, track-and-trace systems support rapid identification and recall of defective or unsafe products. If a product is found to be substandard or contaminated, regulators can quickly identify affected batches and remove them from circulation.

Third, traceability systems improve regulatory oversight of pharmaceutical distribution. By monitoring supply chain activities in real time, regulators can identify irregular transactions, unauthorized distribution channels, or suspicious product movement.

Despite these advantages, the implementation of track-and-trace systems also presents challenges. The successful operation of these systems requires coordination among multiple supply chain actors, including manufacturers, distributors, pharmacies, and regulatory authorities. Ensuring interoperability between different digital systems and maintaining data accuracy are critical factors for effective traceability.

In addition, track-and-trace systems generate large volumes of transactional data. As the number of serialized pharmaceutical packages increases, regulators must process and analyze massive datasets related to product movement and distribution activities. This challenge highlights the need for advanced analytical tools capable of extracting meaningful insights from supply chain data.

Artificial intelligence technologies offer significant potential in this context by enabling automated analysis of pharmaceutical circulation data and identifying patterns that may indicate potential risks.

Artificial intelligence in pharmaceutical supply chain monitoring

Artificial intelligence refers to computational technologies capable of analyzing complex datasets, identifying patterns, and generating insights through

machine learning and advanced data analytics. In recent years, AI has been increasingly applied in logistics and supply chain management to improve operational efficiency and enhance risk monitoring.

Within pharmaceutical circulation monitoring, AI technologies can process large volumes of data generated by track-and-trace systems. These datasets include information on product serialization, distribution transactions, warehouse inventories, and pharmacy dispensing records. By analyzing these datasets, AI algorithms can identify patterns associated with normal supply chain activities and detect deviations that may indicate irregularities.

One of the key advantages of AI technologies is their ability to analyze supply chain data in real time. Machine learning algorithms can continuously monitor distribution activities and detect anomalies as they occur. This capability allows regulators to respond quickly to potential risks in pharmaceutical circulation.

AI-based systems can also improve predictive monitoring of supply chain risks. By analyzing historical distribution data, AI models can identify trends and predict potential disruptions or irregularities in pharmaceutical circulation. For example, unusual spikes in product movement between regions may indicate diversion of medicines to unauthorized markets.

Another important application of AI technologies is the identification of unauthorized supply chain actors. By analyzing transaction networks and distribution patterns, AI algorithms can detect entities that are not authorized to participate in pharmaceutical distribution but appear within supply chain records.

Furthermore, AI technologies can improve regulatory decision-making by providing data-driven insights into pharmaceutical circulation trends. Regulatory authorities can use these insights to identify high-risk distribution

channels, prioritize inspections, and develop targeted regulatory interventions.

Integration of AI and track-and-trace systems

The integration of artificial intelligence with track-and-trace systems represents a significant advancement in pharmaceutical supply chain monitoring. While track-and-trace systems provide visibility into product movement, AI technologies enhance the analytical capabilities of these systems.

In an integrated monitoring framework, track-and-trace systems generate large volumes of supply chain data related to product serialization and distribution activities. This data is stored within centralized databases that record each transaction involving pharmaceutical products.

Artificial intelligence systems can then analyze these datasets to detect anomalies, identify suspicious distribution patterns, and generate alerts for regulatory authorities. Such systems can operate continuously, providing regulators with real-time monitoring of pharmaceutical circulation.

The integration of AI and track-and-trace technologies also supports proactive risk management. Rather than relying solely on manual inspections or reactive regulatory measures, authorities can use AI-driven analytics to identify potential risks before they escalate.

For example, if a serialized pharmaceutical product appears in multiple geographic regions within a short time frame, AI algorithms can flag this activity as suspicious and alert regulator for further investigation. Similarly, AI systems can identify patterns indicating possible diversion of medicines from legitimate supply chains to unauthorized markets.

These capabilities significantly strengthen the ability of regulatory authorities to monitor pharmaceutical circulation and respond to potential risks.

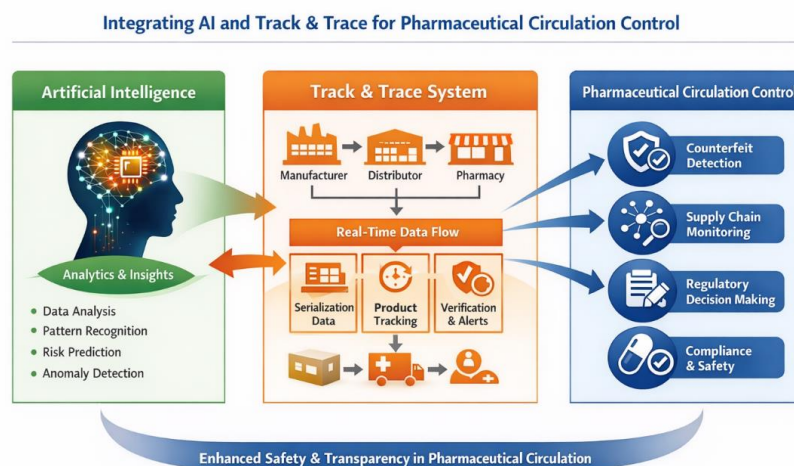


Figure 2: Conceptual Framework of AI-Supported Pharmaceutical Circulation Monitoring.

This framework illustrates how artificial intelligence can analyze real-time data generated by track-and-trace systems to detect anomalies in pharmaceutical circulation and support regulatory decision-making.

Policy implications for Azerbaijan

For Azerbaijan, the implementation of advanced digital technologies for monitoring pharmaceutical circulation represents an important opportunity to strengthen regulatory oversight and improve supply chain transparency.

The development of national track-and-trace systems would enable regulators to monitor the movement of pharmaceutical products across distribution networks. Such systems could provide real-time information on product movement, allowing authorities to verify product authenticity and detect irregular distribution activities.

The integration of artificial intelligence technologies could further enhance these capabilities by enabling automated analysis of supply chain data. AI-driven monitoring systems could support regulatory authorities in identifying suspicious distribution patterns, unauthorized supply chain actors, and potential diversion of medicines.

Implementing these technologies would also contribute to broader digital transformation efforts within the healthcare sector. By adopting modern digital infrastructure for pharmaceutical monitoring, Azerbaijan could strengthen regulatory efficiency and align its pharmaceutical circulation monitoring systems with international best practices.

However, successful implementation requires addressing several challenges. These include the development of appropriate regulatory frameworks for digital monitoring systems, ensuring interoperability between different supply chain actors, and maintaining robust cybersecurity measures to protect sensitive supply chain data.

Capacity building is also essential for the effective use of advanced digital technologies. Regulatory authorities must develop technical expertise in data analytics, artificial intelligence, and digital supply chain monitoring.

Despite these challenges, the potential benefits of AI-supported track-and-trace systems are significant. These technologies can improve transparency, strengthen regulatory oversight, and enhance the safety of pharmaceutical circulation.

Future directions for digital pharmaceutical circulation monitoring

The rapid development of digital technologies suggests that pharmaceutical circulation monitoring will continue to evolve in the coming years. Emerging technologies

such as blockchain, Internet of Things (IoT) sensors, and advanced data analytics may further enhance supply chain transparency.

Blockchain technology has been proposed as a potential solution for improving data integrity in pharmaceutical supply chains. By creating decentralized and tamper-resistant records of supply chain transactions, blockchain systems could further strengthen traceability and reduce the risk of data manipulation.

Similarly, IoT technologies can be used to monitor environmental conditions during pharmaceutical transportation and storage. Sensors embedded in pharmaceutical packaging can provide real-time data on temperature, humidity, and other environmental factors that may affect product quality.

Artificial intelligence will likely play a central role in integrating these technologies into comprehensive pharmaceutical circulation monitoring systems. AI-driven platforms could analyze data from multiple sources—including track-and-trace systems, IoT sensors, and regulatory databases—to provide a holistic view of pharmaceutical supply chains.

Such integrated systems could transform pharmaceutical circulation monitoring from reactive regulatory oversight into proactive risk management.

For countries seeking to modernize pharmaceutical regulation, the adoption of digital monitoring technologies represents a strategic opportunity to enhance supply chain transparency and protect public health.

CONCLUSION

Ensuring the safe circulation of pharmaceutical products is essential for protecting public health and maintaining trust in healthcare systems. Traditional regulatory mechanisms often lack the capacity to provide real-time visibility into complex pharmaceutical supply chains.

Digital track-and-trace systems and artificial intelligence technologies offer powerful tools for improving transparency and regulatory oversight in pharmaceutical circulation. By enabling advanced monitoring and data analysis, these technologies can significantly strengthen the safety and security of pharmaceutical supply chains.

For Azerbaijan, integrating artificial intelligence technologies with national track-and-trace systems represents an important opportunity to modernize pharmaceutical regulation, enhance transparency in medicine distribution, and improve the safety of pharmaceutical circulation.

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