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ECONOMICS AND MANAGEMENT IN CONDITIONS OF MILITARY CHALLENGES

Collective monograph
edited by A. Pawlik, K. Shaposhnykov

IZDEVNIECĪBA BALTIJA PUBLISHING
2025

UDK 33(082)
Ec800

Recommended for publication
by the Academic Council of State University of Jan Kochanowski

The authors of articles usually express their own opinion, which is not always comply with the editorial Board's opinion. The content of the articles is the responsibility of their authors.

Economics and Management in Conditions of Military Challenges : Collective monograph. Riga, Latvia: Baltija Publishing, 2025. 580 p.

ISBN 978-9934-26-628-7

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DOI: https://doi.org/10.30525/978-9934-26-628-7-25

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THE ROLE OF TECHNOLOGICAL TRACING IN THE MODERNIZATION OF UKRAINE'S EXPORT-IMPORT ACTIVITIES

Summary

In the contemporary context of international trade development, a critical challenge lies in ensuring transparency, security, and efficiency in managing increasingly complex export and import operations. These complexities arise due to the growing number of participants, volume of goods, and financial flows. The absence of reliable mechanisms for control and traceability exacerbates risks of fraud, delays, losses, and disruptions within supply chains, adversely affecting the competitiveness of economic entities and states in the global economic environment. This research examines the application of technological tracing in export-import processes as an effective tool to address these challenges. It analyzes the integration of advanced digital technologies that provide comprehensive control and real-time monitoring of goods movement and financial transactions, enhancing data accuracy and integrity, automating processes, and integrating information systems among supply chain participants. Special attention is given to identifying the fundamental principles underpinning tracing systems, including transparency, data reliability, automation, integration, continuous monitoring, regulatory compliance, and feedback mechanisms, which ensure adaptability and improved efficiency of management processes. The study also examines key management functions supported by technological tracing, including strategic planning, operational control, risk management, customs and regulatory compliance, and business process optimization. The findings demonstrate that implementing technological tracing contributes to reducing operational costs, accelerating logistics processes, strengthening trust among trade participants, and increasing overall competitiveness in the international arena. The research further formulates recommendations for advancing the integration of tracing systems with international information platforms, harmonization with global standards, and the development of normative and organizational frameworks to ensure their effective utilization. Emphasis is placed on the promising role of public-private partnerships and the expanded application of tracing technologies in environmental safety, product quality control, and intellectual property protection.

Introduction

Globalization and digitalization in the modern global economy fundamentally transform export-import activities, rendering them increasingly dynamic, integrated, and technologically advanced. These transformations necessitate the deployment of effective mechanisms for monitoring, controlling, and managing goods flows across all stages of the supply chain. Technological tracing enhances transparency, security, and efficiency in foreign economic operations. It enables comprehensive traceability of goods, identification of their origin, verification of compliance with international standards, and the optimization of customs procedures.

International experience demonstrates the growing implementation of tracing systems within the framework of intergovernmental initiatives, such as the GS1 Global Traceability Standard [1], reflecting the increasing relevance of such mechanisms in the contemporary global economy. For Ukraine, which has declared a strategic course toward European integration and aspires to become a full-fledged member of the European single market, a dual imperative arises: harmonizing national legislation with EU norms and undertaking a comprehensive modernization of export-import infrastructure through digital transformation. Under the conditions of complex transnational supply chains, the state's ability to incorporate technological tracing into export-import operations is becoming a critical factor in enhancing national competitiveness, ensuring the transparency and security of trade transactions, and supporting the emergence of innovative business models. Given Ukraine’s high dependence on foreign trade, the advancement of technological tracing emerges as a particularly urgent priority. It has the potential to ensure conformity of Ukrainian products with EU technical regulations, facilitate participation in joint digital initiatives, and demonstrate the technological maturity of Ukraine’s foreign trade sector to prospective investors.

One of the key priorities of Ukraine’s economic policy amid the digital transformation of the global economy is enhancing export-import performance through the adoption of advanced digital technologies, with technological tracing occupying a central position. In the course of harmonization with European standards and regulations, integrating such mechanisms may become a crucial factor in modernizing the country’s foreign economic activity. The application of technological tracing in Ukraine is regarded as a strategically important step toward the digital transformation of trade, aimed at increasing its competitiveness in the international marketplace.

This study examines the role of technological tracing in modernizing Ukraine’s export-import operations within the broader context of digitalization in international trade.

To achieve this objective, the following research tasks are pursued: to analyze the current state and key evolutionary trends of technological tracing in the global economy; to investigate digital technologies employed in the implementation of tracing systems within export-import activities; to outline the fundamental principles, core objectives, and functions of technological tracing in the context of trade modernization.

The fulfillment of these tasks will contribute to developing a comprehensive approach to implementing technological tracing, enabling more effective management of export-import flows and strengthening Ukraine's position in the global economy. The study's methodological framework is based on a systems approach, incorporating the analysis of academic sources, the synthesis of theoretical concepts, the examination of international practices, and the assessment of the application of technological tracing in export-import operations.

Chapter 1. Theoretical foundations of technological tracing in the international economy and the main directions in modernizing export-import activities

In academic literature, the concept of "tracing" (from the English *tracing* – tracking, monitoring) is interpreted as a mechanism that enables the identification of a product's origin, its movement history, storage conditions, and handling processes, as well as the recognition of key stages within the production and logistics cycle. Tracing technology has undergone substantial evolution, from its initial application in software development to its current role in supply chain management and ensuring transparency across various sectors.

During the 1960s and 1970s, the term *tracing* emerged in information technology, where it was employed to analyze program performance, debug code, and monitor process execution within operating systems. Over time, as technological capabilities expanded, the meaning and scope of tracing broadened significantly. According to the Codex Alimentarius Commission [2], tracing refers to the ability to follow the movement of a food product through all stages of production, processing, and distribution.

By the 1980s, tracing concepts had been adapted for logistics, particularly for tracking goods and services throughout the supply chain. Automating cargo registration and transportation during this period resulted in a significant improvement in flow control accuracy and a reduction in errors in supply chain operations [3].

A significant advancement occurred with the introduction of automatic identification technologies, such as barcodes and radio-frequency identification, which significantly enhanced the precision and efficiency of tracking systems. Since the 1990s, these tools have become integral components of logistics operations, facilitating continuous monitoring of goods from production to final delivery and enabling real-time data acquisition regarding product movement [4].

In the 2000s, particularly with the rise of the Internet of Things and blockchain technologies, tracing systems gained new opportunities for integration and automation. Blockchain, in particular, enabled the creation of transparent and immutable ledgers, significantly enhancing trust in product tracking processes across supply chains and ensuring protection against data manipulation and fraud [5]. When combined with Internet of Things technologies that allow real-time data collection from sensors and devices, modern tracing systems deliver highly accurate and timely information on goods, production processes, and distribution operations [6].

During the 2020s, the term "tracing" gained renewed attention amid the COVID-19 pandemic, when contact tracing emerged as a critical tool in controlling the spread of the virus. This context highlighted the broader relevance of tracing mechanisms across essential sectors. It has also demonstrated the importance of identifying safety risks promptly and implementing rapid response measures, particularly in the food and pharmaceutical industries. For instance, tracing in the pharmaceutical sector plays a crucial role in preventing drug counterfeiting and safeguarding patient health [7].

As conventional tracking methods become insufficient to meet the increasing demands for precision, speed, and data security, technological tracing has gained momentum based on the convergence of advanced digital tools. This approach integrates Artificial Intelligence, blockchain, the Internet of Things, privacy preservation, Radio Frequency Identification, and big data analytics. Today, tracing technologies extend beyond logistics and are widely applied in various industries, including pharmaceuticals, agri-food, energy, healthcare, and others. Incorporating digital innovations such as Artificial Intelligence, cloud computing, and data analytics significantly expands the capabilities of tracing systems, enabling real-time tracking and optimizing decision-making processes, production efficiency, and cost reduction.

The progression of tracing technologies – from basic tracking tools to sophisticated digital ecosystems – reflects a steady transformation shaped by advances in information technologies. Early systems focused on physical monitoring methods, including barcodes and Radio Frequency Identification (RFID), which enabled product tracking at specific stages of the supply chain. However, the evolution of global economic systems and the growing need for transparency and efficiency prompted the development of more complex and integrated solutions. The synergy of blockchain, Internet of Things, Artificial Intelligence, and big data has led to the emergence of highly robust tracing architectures capable of continuous monitoring and end-to-end visibility throughout the entire product lifecycle.

In export-import operations, technological tracing is evolving into a comprehensive system of digital tools and innovations designed to collect, process, and analyze data on product movement across all stages – from production to final delivery. Its primary objective is to ensure complete transparency in supply chains, thus enhancing the regulatory framework of international trade. At the global level, technological tracing is a vital mechanism for customs security, counterfeit prevention, logistics optimization, and enforcement of environmental and sanitary standards.

As a mechanism for modernizing export-import activities, the implementation of technological tracing is based on several theoretical concepts that explain its significance, functionality, and impact on economic processes. These concepts help identify the key factors contributing to the effectiveness of tracing systems and reveal the role of such technologies in transforming approaches to managing supply chains, transportation, and product control in international markets. In particular, the *concept of global value chains* views technological tracing as a crucial tool for optimizing production and logistics processes. The traceability of goods and information flows within global supply chains promotes the transparency of economic relations, ensures quality control, and minimizes risks. For instance, the research [8] highlights the need for further studies to examine the optimal level of tracking for different industrial sectors and supply chain configurations. The *theory of digital transformation* focuses on the impact of modern information and communication technologies, particularly the Internet of Things, blockchain, and big data analysis, on the efficiency of goods flow management. The use of digital technologies enhances the level of automation in technological tracing processes, ensuring the accuracy and speed of information processing. The findings [9] demonstrate the significant role of digital transformation in enhancing supply chain capabilities, which in turn positively influences sustainable competitiveness. *Customs theory and regulation* emphasize the importance of tracing systems in customs control and simplifying customs procedures. The implementation of tracing mechanisms helps reduce the level of counterfeiting, improve the monitoring of goods crossing borders, and ensure compliance with international trade regulation standards. The challenges that customs authorities face due to the growing volume of cross-border e-commerce, particularly regarding data quality and tax issues, are addressed in the work [10], which highlights the need for accurate data to effectively control and regulate customs procedures. Within the *framework of sustainable development theory, technological tracing systems are a crucial* tool for ensuring environmental sustainability and social responsibility among participants in export-import activities. The traceability of products throughout their entire lifecycle supports adherence to ecological standards, minimizes the negative environmental impact, and promotes ethical practices in international trade. Tracking the sources of product origin, production conditions, and logistics enables the formation of supply chains that adhere to principles of social justice, transparency, and ecological compliance. In this context, the study [11] underscores the importance of sustainable trade development as a factor in economic growth, emphasizing the positive impact of rational resource use, increased productivity, rising incomes, and investments on the long-term stability of the global economy.

Thus, technological tracing integrates into various conceptual approaches of international economics, ensuring its multidimensional impact on the development of export-import activities. Within this multifaceted framework, the conceptual foundations of tracing serve as a scientific and analytical framework, forming the basis for the practical implementation of effective mechanisms for managing commodity flows in the face of growing challenges, including globalization, digitalization, and the regulatory complexities of export-import activities. These foundations enable us to view tracing as a strategic tool for ensuring the transparency, legality, safety, and sustainability of international trade. This approach opens prospects for harmonizing institutional approaches, developing adaptive management solutions, and integrating digital technologies into export-import operations.

The multifaceted nature of technological tracing is determined by the fact that it emerges at the intersection of several scientific fields, which defines its complex nature and wide functional application in international trade. In this regard, the theoretical foundations of technological tracing should be viewed as an interdisciplinary category that combines elements of global economics, information technologies, logistics, supply chain management, and state regulation of foreign trade. This scientific synergy enables a comprehensive understanding of the role and functional significance of tracing within global economic relations.

From the perspective of *international economics*, technological tracing contributes to the reduction of non-tariff barriers, enhances the efficiency of customs administration, and creates conditions for the free exchange of goods and services. Ensuring the transparency of commodity flows within international supply chains fosters trust among trade participants, improves the quality of trade interactions, and facilitates compliance with international agreements and standards [12]. As a result, technological tracing becomes one of the key instruments for modernizing the export-import activities of countries, particularly those integrating into the EU's common market.

The functioning of tracing in the contemporary digital environment is impossible without the use of *information technologies*. These technologies enable the real-time monitoring and processing of data on the movement of goods. Automated data collection systems, digital platforms, blockchain technologies, GPS navigation, and Artificial Intelligence tools ensure the accuracy, timeliness, and reliability of the information accompanying products at all stages of their movement [13]. Furthermore, using digital solutions helps identify and localize violations or risks, which is critical for ensuring consumer safety and compliance with international regulations.

Equally important is the role of technological tracing in *logistics and supply chain management*. The traceability of goods at each stage of the journey – from manufacturer to final consumer – enhances forecasting accuracy, optimizes transportation routes, and minimizes logistics costs and delays. As a result, tracing serves not only as a control tool but also as a mechanism for improving the efficiency of logistics operations, which is especially crucial in the face of the high dynamics of global markets and the complexity of supply chains [14].

From a *policy* perspective, technological tracing is viewed as an essential regulatory tool, particularly in issues related to security, compliance with technical regulations, and combating illegal practices in foreign trade. Government agencies use tracing systems for customs surveillance, risk assessment, product certification, and monitoring the origin of goods. For instance, the European Commission identifies digital product identification as one of the conditions for market access within the EU, particularly through the initiative of the digital product passport [15].

Thus, technological tracing results from integrating knowledge and approaches from several scientific disciplines. This enables the creation of comprehensive and effective mechanisms for managing international commodity flows that address the modern challenges of the global economy, due to its interdisciplinary nature, tracing functions not only as a technical tool but also as a strategic factor in enhancing transparency, security, and foreign trade competitiveness in the context of digital transformations.

Therefore, technological tracing in the context of export-import activities presents itself as a complex interdisciplinary system encompassing technical and institutional components to ensure transparency, responsibility, and efficiency in international trade. Its evolution from simple technical accounting tools to complex digital ecosystems reflects the transformation of the economic reality where knowledge, information, and the speed of data exchange are becoming critical resources. Technological tracing is significant not only as a tool for operational control but as the foundation of a new logic for managing trade processes, focused on adaptability, responsibility, and trust among all participants in the global economic space. This approach lays the foundation for transitioning from the fragmented use of tracing solutions to integrated strategies for the digital transformation of export-import activities, aligning with the demands of the modern stage of global trade development.

The definition of theoretical foundations for technological tracing provides the basis for a scientific-methodological analysis of the key directions for its practical implementation in export-import activities. In this context, systematic research into scientific approaches that reveal the mechanisms of applying technological tracing in transforming foreign economic processes becomes essential. Considering the growing importance of transparency, security, and digital integration in global supply chains, scientific studies in tracing play a crucial role in shaping new methods, tools, and regulatory approaches. Therefore, a scientific-methodological analysis of the current state of research in this area helps identify the leading directions for the development of tracing technologies in the export-import sphere and outlines the prospects for their practical application in the Ukrainian context. A review of scientific works, developments, and international practices will contribute to the formulation of scientifically grounded recommendations for integrating innovative tracing solutions into national foreign economic activities.

It is worth noting that scientific research related to the development of export-import activities and the digital transformation of their business processes is actively progressing. For instance, the paper [16] outlines the advantages and challenges of implementing digital technologies in the marketing and logistics systems of industrial enterprises. This is crucial for the further development of technological tracing systems. The work [17] emphasizes that modern information technologies form the foundation of the competitiveness of states and individual companies in the global market. In [18], the significance of using digital tools in marketing and logistics activities is also discussed, highlighting that integrating these tools optimizes supply chains, personalizes customer interactions, reduces costs, and enhances profitability. The analysis confirms the need for digital transformation in foreign trade [19], demonstrating that logistics productivity factors, such as customs efficiency, infrastructure quality, and the reliability of shipment tracking, significantly improve economic performance. Therefore, digital technologies, which form the foundation of technological tracking, enable the creation of effective systems for tracking goods and services in global supply chains.

Thus, *technological tracing of supply chains* is one of the key areas for modernizing export-import activities, as it ensures greater transparency and control over the movement of goods from producers to the final consumer. By implementing modern digital technologies, businesses can manage their logistics processes more effectively, reduce costs, and enhance supply reliability. Supply chain tracing increases the efficiency of internal economic processes. It facilitates the integration of national economies into global trade networks, marking a significant step toward modernizing export and import activities.

Effective tracing of supply chains is impossible without transparent and efficient customs procedures, as customs authorities are responsible for controlling the movement of goods across borders. Therefore, using digital platforms to monitor the movement of goods requires data synchronization with customs authorities and integration with electronic customs systems. Compliance with international standards and regulatory requirements is essential for effective technological tracing. Proper handling of certificates of origin during customs procedures is crucial to ensure compliance with trade agreements, accurate tariff and duty determination, prevent fraud, and promote efficient trade. The article [20] analyzes the requirements for import customs clearance procedures under preferential trade agreements, discusses the unique attributes of Distributed Ledger Technology (DLT), and presents the application of DLT in customs procedures and international trade.

Another critical aspect of supply chain tracing is *ensuring compliance with trade norms* that regulate export and import activities. Adherence to these norms guarantees the legitimacy of transactions and facilitates the seamless movement of goods across international borders. The study [21] provides a comparative analysis of the implementation of technological tracing and its impact in OECD member countries. Using a multidimensional analytical framework, the study examines national regulations, legislative frameworks, and key food products affected by the introduction of digital tracing tools. The authors also evaluate the effectiveness of these tools in meeting consumer transparency expectations, complying with regulatory requirements, and achieving the primary goal of sustainable development of the agricultural and food supply chain. The research [22] argues that traceability is the best global implementation. This implies that countries need accreditation and certification processes that recognize equivalency. The authors examine two common approaches – national regime and mutual recognition. Under the national regime, importers must comply with domestic tracking rules and adopt nearly identical tracking processes. Through mutual recognition, countries officially acknowledge that if products meet foreign standards, they de facto comply with domestic standards and can be imported without further restrictions. Mutual recognition is a more favorable approach, allowing countries to accept different methods to achieve the same objectives. Therefore, compliance tracing with trade norms is a vital area of transformation for export-import activities, as it ensures that goods and services meet international standards, security requirements, quality standards, and environmental requirements. This enables tracking every stage of the production and transportation of goods to ensure they comply with applicable trade norms and regulations. The implementation of tracing technologies reduces the risk of non-compliance and enhances trust between participants in export-import activities, particularly by ensuring transparency in certification and control processes.

Ensuring compliance with trade norms is crucial in the supply chain, as it ensures adherence to international standards, customs requirements, and export and import regulations. However, financial transparency and control are key to effective export-import activity alongside regulatory compliance. Given the complexity of financial flows associated with cross-border shipments, financial tracing becomes an essential element. This process enables monitoring all financial transactions related to purchasing, transporting, and selling goods, including foreign exchange operations and payment obligations. The study [23] examines the impact of financial and trade openness on economic growth in ten countries from 1970 to 2023. In the context of increasing geo-economic tensions, trade fairness, and national security concerns, the authors emphasize the need for policies that strike a balance between integration into global financial and trade systems and national interests. The research [24] explores how supply chain financing can contribute to achieving sustainable growth for enterprises. This study demonstrates that supply chain financing has a significant impact on the stable development of companies, particularly in commercial and trade enterprises, as well as regional businesses with more developed financial systems. Based on the findings of this research, the authors developed recommendations for implementing dynamic financial risk management, utilizing real-time data for monitoring financial health, and applying flexible financial products in the supply chain to optimize capital efficiency. Adopting such technologies enables companies to quickly adjust their strategies, identify potential threats, and optimize financial resources – a crucial element of financial tracking. Therefore, introducing financial tracing in export-import operations is a necessary condition for effective management of financial flows and mitigating the risks associated with cross-border transactions. The use of advanced technologies for real-time financial transaction monitoring, along with flexible financial instruments, is a critical aspect of this process, enhancing the stability and efficiency of export-import activities.

Given the importance of financial tracing in ensuring the efficiency of export-import activities, it is also crucial to consider the technological aspects contributing to the automation and enhancement of financial transaction tracking processes. One such innovative approach is *distributed technological tracing on trading platforms*, which, through cutting-edge technologies, ensures transparency and security of financial operations within trading platforms. This type of tracing enables real-time tracking of transactions and automates many stages, thereby reducing the risks associated with human error and operational mistakes. Although the study [25] does not directly address the issue of distributed tracing in the context of export-import activities, the approaches outlined by the authors regarding transparency, accountability, and monitoring within the global value chain, particularly in the textile and clothing sector, may be relevant to similar challenges in distributed digital infrastructures. Creating an independent platform for storing critical information, shared by all participants in the process but not controlled by any single entity, is conceptually aligned with modern approaches to implementing distributed tracing on trading platforms. The issue of traceability and ownership verification in the environment of distributed trading of digital assets is addressed in the work [26], where the authors propose a proof-of-ownership schema (DOCS) to ensure the integrity, accountability, and security of transactions within a blockchain infrastructure. This approach is conceptually aligned with the goals of distributed tracing on trading platforms, where it is crucial to ensure transparency at all transaction stages, event chain reproducibility, and precise identification of responsible parties in the event of violations. The relevance of applying distributed tracing technologies to ensure transparency and authenticity on digital trading platforms is also confirmed in the study [27], dedicated to the digitization of the EU Emissions Trading System. In this work, the authors justify the adoption of distributed ledger technology (DLT) to ensure traceability, ownership verification, and real-time monitoring of the carbon certificate lifecycle. The proposed DLT-based platform enables the verification of accounting data authenticity, conducts trade record audits, and ensures decentralized reporting, thereby creating conditions that enhance trust among market participants, minimize fraud risks, and effectively support regulatory policy. Thus, the development of distributed technological tracing on trading platforms is a logical continuation and improvement of financial tracing, enabling the integration of technologies to enhance the efficiency and security of international financial transactions. As export-import activities increasingly transition to the digital domain, distributed technological tracing evolves from a technical monitoring tool to a strategic risk management mechanism, enhancing efficiency and strengthening trust between international trade partners. Its implementation contributes to the formation of a sustainable, transparent, and accountable digital infrastructure for the global market.

An analysis of scholarly sources indicates that, among the primary directions in the development of technological tracing, supply chain tracing, and compliance tracing –particularly in the context of food safety – remain key areas of focus. For instance, the study [28] explores the integration of blockchain technologies with privacy-preserving mechanisms in food traceability systems. The authors emphasize the challenges of ensuring supply chain transparency while safeguarding personalized data, which is particularly relevant for creating a secure and trustworthy international trade environment. This research exemplifies the intersection of supply chain tracing and regulatory compliance, requiring simultaneous adherence to food safety standards and digital ethics. In turn, the work [29] focuses on "smart" tracing, which relies on the Internet of Things, cloud computing, and big data to develop dynamic, real-time food tracking systems. The authors emphasize the significance of these technologies in enhancing supply chain reliability and ensuring adherence to international quality and safety standards. This study also addresses supply chain tracing in conjunction with trade compliance, demonstrating how innovative technologies contribute to improved management of product flows and enhanced control over product conformity.

The synthesis of scientific approaches to implementing tracing systems, particularly in food safety, supply chain transparency, and compliance with international standards, provides a basis for classifying the directions of technological tracing according to their functional characteristics and practical applications in export-import operations. Such systematization enables a more comprehensive assessment of the potential of digital solutions across various implementation domains, helping to identify key technologies that ensure the effective operation of traceability systems.

Chapter 2. The digital technologies, principles, and functions of technological tracing in export and import activities

Each of the areas of technological tracing involves the integration of digital technologies that enable comprehensive control over all stages of the movement of goods and services, from producers to end consumers. Digital technologies are rapidly transforming business operations, particularly in international trade and supply chains. Their impact on supply chains, customs procedures, and financial transactions opens up new opportunities for increasing efficiency, transparency, and security. In this context, special attention should be given to technologies such as the Internet of Things (IoT), Radio-Frequency Identification (RFID), Blockchain (BC), Artificial Intelligence (AI), Robotic Process Automation (RPA), as well as advanced systems for financial transaction processing, including SWIFT GPI and Central Bank Digital Currencies (CBDCs).

Contemporary scientific research has demonstrated the practical implementation of these technologies across various sectors, highlighting their potential to enhance efficiency, security, and transparency in supply chain management and financial operations. Therefore, it is advisable to utilize the findings of these studies to gain a better understanding of the implementation and integration of the aforementioned digital technologies in the context of export-import activities.

One of the most transformative technologies in supply chain management is the IoT, which enables continuous monitoring of goods throughout all delivery stages. Through IoT, it is possible to track critical parameters such as temperature, humidity, and geolocation, which are essential for maintaining product quality, especially in the case of sensitive goods like pharmaceutical products or food items. The global IoT market in supply chain management is projected to reach USD 41.8 billion by 2033 [30]. The study [31] demonstrated that data analytics and IoT technologies can significantly enhance the operational efficiency and customer experience in e-commerce. These technologies support the internal development of e-commerce enterprises and play a substantial role in strengthening their international competitiveness.

RFID and QR codes are becoming integral components of process automation in goods tracking, especially at customs checkpoints and within logistics networks. RFID enables contactless identification of goods through specialized tags, allowing customs authorities to quickly inspect shipments and reduce the likelihood of human error during inspections. The study [3] proposes implementing a prototype asset tracking system using RFID technology, designed to be adaptable and applicable across diverse industrial settings. The results presented by the authors demonstrate a notable increase in production efficiency, accompanied by significant optimization. This successful implementation highlights the potential of RFID technology to enhance operations, reduce labor time, and improve traceability in industrial production processes. Based on a survey [32], the research examines how RFID technology can enhance competitive advantage in the pharmaceutical supply chain and identifies the barriers and solutions to its implementation. Key areas for RFID adoption were identified as distribution (72.40%), warehousing (53.40%), reverse logistics (48.30%), and manufacturing (24.10%). At the same time, the authors highlight the main challenges associated with RFID implementation: high costs of RFID devices (60.34%), limited industry understanding of RFID applications (58.62%), and the cost of accompanying software (44.83%). The study [33] examines the application of QR codes on food products to enhance transparency and traceability throughout supply chains. According to the authors, QR codes enable consumers and businesses to instantly access information about a product's origin, thereby enhancing trust and improving the effectiveness of tracking. They also emphasize the importance of integrating this technology into supply chains to facilitate product identification and verification at customs, as well as to enhance interaction between producers, distributors, and end consumers.

BC is another crucial technology ensuring supply chain transparency and data integrity. It allows all transactions to be stored in an immutable ledger, accessible to all participants in the chain, providing complete transparency of processes and minimizing opportunities for fraud or manipulation. The study [34] explores how BC technology revolutionizes logistics by enhancing transparency and reducing delays in international trade. The analysis presented in this work demonstrates that the ability to track shipments and verify transactions in real-time enhances the resilience of the supply chain to disruptions, making BC a vital tool in modern logistics management. BC creates a distributed database that stores all transactions within the supply chain, making them immutable and resistant to falsification. Research [35] demonstrates that BC can significantly enhance security and transparency in export-import activities. The article [36] also highlights the advantages of BC for improving the traceability, security, and efficiency of supply chains. As an extension of this digitalization aspect, the study [6] explores the potential of integrating BC and IoT to ensure end-to-end visibility, secure data exchange, and real-time monitoring within the supply chain ecosystem. The impact of digital transformations such as BC technology, the Social Internet of Things (SIoT), and AI on supply chains for tracking and transparency creation is analyzed in the work [37], where it is shown that, along with transparency, efficiency is also improved.

Meanwhile, the study [38], which aimed to assess the effectiveness and economic benefits of BC technology in financing export-import activities, shows that implementing BC technology can enhance operational efficiency and mitigate transactional risks. However, it also demonstrates that this comes at the cost of increased expenses, making it unsuitable for widespread adoption due to its unfavorable net benefit. In the work [4], a blockchain-based supply chain model is proposed, along with smart contracts to define terms and requirements between participants and the application of RFID and IoT technologies for tracking goods.

AI and machine learning play a crucial role in processing the vast amounts of data generated throughout all stages of supply chains. AI enables the automation of customs declaration analysis, forecasting of violations, and detection of suspicious financial transactions. Specifically, machine learning can identify patterns in financial transactions, such as abnormal transfers or changes in business practices, which may indicate potential instances of fraud or money laundering. The study [39] explores the integration of AI with BC technology within the ABI Schain platform to address challenges in IoT-based supply chains, focusing particularly on delays, scalability, and data consistency. The work [40] examines the role of AI in transforming international trade. The author comprehensively analyzes how AI technologies change trade dynamics and identifies key challenges and opportunities. The study also presents examples of companies that have successfully leveraged AI to gain competitive advantages. Research [41] confirms that AI know-how enhances productivity and efficiency while strengthening supply chain resilience and sustainability. AI has the potential to transform the way supply chains operate, enabling real-time decision-making and facilitating operational adaptability.

RPA also contributes to optimizing routine and repetitive tasks, such as processing customs declarations or verifying document compliance. This technology uses software robots to automate workflows, significantly reducing processing time and minimizing the occurrence of errors. In customs control, RPA can automate document scanning, form filling, and interact with government databases to verify information about exporters and importers. By implementing RPA, customs authorities can reduce employee workload, accelerate verification processes, and enhance security levels [20].

SWIFT GPI is actively used to optimize international financial transactions – a technology that enables real-time tracking of global payments. This system ensures payment transparency, reducing the risk of delays and errors during transactions. At the same time, as a new technology, Central Bank Digital Currencies (CBDCs) can become an essential tool for reducing the costs of international transfers and enhancing currency stability in trade. CBDCs help lower transaction costs and promote greater transparency in global financial operations, which is particularly important for businesses that engage in numerous cross-border payments [24].

Open Telemetry is used for performance monitoring and analysis of distributed systems in export-import platforms. It enables real-time transaction tracing, timely issue identification, and uninterrupted platform operations. In conjunction with this, Big Data enables the processing of large volumes of data to predict risks and optimize operations across all stages of the supply chain. Big Data analytics enables companies to analyze trends, consumer preferences, and even market demand, which aids in better planning and more accurate inventory management. Predictive analytics allows businesses to forecast future trends and risks, making them more flexible and adaptive to changes in the economic environment [8]. The study [42] explores the integration of business analytics and Big Data analytics, fostering the development of business competitive advantage. The authors identified the potential to utilize various data sources, providing organizations with a comprehensive understanding of market trends, consumer behavior, and operational efficiency. This, in turn, enables decision-makers to make informed and timely choices, enhancing overall organizational flexibility and responsiveness to market dynamics.

Thus, each identified digital technology corresponds to a specific direction of technological tracing – from logistics to finance – and helps solve tasks at various stages of export-import activities. The application of digital technologies in tracing contributes to reducing operational costs, increasing the speed of turnover, optimizing logistics, and enhancing trust between counterparties, which is especially important in the context of the growing complexity and dynamics of global trade.

Defining the key directions of technological tracing and the primary digital technologies used in this process is a crucial step in its implementation. However, for the effective functioning of tracing systems, it is necessary to implement modern digital technologies and ensure the methodological and organizational foundation for their application. This is only possible if clear principles are established to regulate their operation, ensuring the integration and systematic use of tracing technologies in export and import activities.

In this context, key principles include transparency, data reliability, automation, integration, continuous monitoring, regulatory compliance, and feedback. These principles are crucial in creating an effective and secure technological tracing system.

The first important principle is the *principle of transparency*. Transparency at all stages of the supply chain ensures efficient tracking and verification of product information. Using technologies such as blockchain ensures reliable access to data on the movement of goods, customs clearance, financial transactions, and other critical elements. As noted in the work [8], BC reduces the risk of data falsification, as all transactions are immutable and visible to participants in the supply chain. This, in turn, ensures a high level of transparency, allowing each participant to verify the product's authenticity.

The second key principle is the *principle of data reliability*. To ensure high data accuracy, technologies must be used to verify and protect product data from potential counterfeiting or manipulation. RFID tags and QR codes are significant for product identification in this context. Research [4] indicates that these technologies, when combined with BC systems, guarantee the preservation of data accuracy and prevent any changes in the product's history, which is crucial for maintaining trust among trade participants.

The following principle is the *principle of automation*, which involves utilizing modern technologies to collect and process data automatically. The use of IoT and automated monitoring systems significantly increases tracing efficiency. With the help of sensors and detectors, the condition of the product and its location can be continuously tracked. The work [39] emphasizes that process automation reduces data processing time, decreases the likelihood of errors, and ensures timely responses to changes in the supply chain.

The *principle of integration* is also a vital aspect of technological tracing. The integration of various technological platforms and systems enables supply chain participants to interact effectively. This is especially important to ensure continuous data exchange between customs authorities, transport companies, and other process participants. The authors [25] note that integrating BC technologies with various platforms, particularly IoT, ensures a high level of synchronization among all participants, thereby increasing efficiency and reducing the risks of delays or errors in the product processing process.

The *principle of continuous monitoring* is also critically important for ensuring the stability of the tracing process. Constant monitoring using GPS systems and sensors enables the collection of real-time data, which is crucial for promptly identifying issues and deviations from the plan. As noted in the work [37], real-time monitoring systems enable timely responses to violations or delays, thereby significantly improving delivery efficiency and reducing business risks.

The next important aspect is the *principle of compliance with regulatory standards*, as all tracing technologies must adhere to international security and data confidentiality standards. Using technologies that comply with regulations helps avoid legal issues and sanctions from customs authorities. As demonstrated in the work [38], BC technologies can help ensure compliance with regulatory requirements, particularly those related to data protection and customs regulations.

Another essential principle is the *principle of feedback*, which involves using systems that enable timely responses to changes and facilitate process optimization. Artificial intelligence-based systems can predict deviations and automatically adjust the supply chain, reducing the likelihood of errors and improving efficiency. As emphasized by the authors [41], utilizing AI for forecasting and correcting processes enables the timely identification and correction of deviations, which is particularly crucial in the context of export-import activities.

Thus, the principles on which technological tracing in the field of export-import activities is based include transparency, data accuracy and integrity, process automation, integration of information systems, continuous monitoring of operations, compliance with current regulatory standards, and an effective feedback mechanism. Implementing these principles helps form an innovation-oriented supply chain management infrastructure, ensuring appropriate control and traceability of goods movement and minimizing logistical, financial, and regulatory risks. Considering the outlined directions for the development and principles of technological tracing, further research into its integration into the overall export-import operation management system is advisable.

The features of technological tracing determine its ability to implement several key management functions that directly impact the effectiveness of export-import processes.

Among these functions are:

- the *strategic planning function*, which provides managers of enterprises, companies, and government bodies with analytical information about the dynamics of goods flows, the structure of exports and imports, enabling the formation of long-term forecasts, identification of promising markets, and adjustment of the strategy for the development of export-import activities; in this context, researchers [25] emphasize the importance of such information for forecasting demand and orienting towards new markets;
- the *monitoring and control function*, which ensures real-time tracking of goods movement at all stages of the logistics chain, enabling prompt response to transportation violations, delivery delays, or non-compliance with product standards; this aligns with the conclusions of the study [37], where it is noted that real-time monitoring significantly enhances the effectiveness of logistics operations;
- the *regulation and compliance function*, which helps government authorities control the adherence of exporters and importers to customs legislation, international standards, and certification requirements, contributes to the harmonization of the regulatory framework with EU and WTO regulations; as stated by [38], the

integration of technologies with regulatory requirements enables the creation of transparent and efficient customs systems;

- the *customs administration optimization function*, which simplifies cargo verification, reduces clearance time, lowers administrative barriers, and decreases opportunities for corruption; this is confirmed by the results of the study [4], where the positive impact of digital tools on the effectiveness of customs regulation is emphasized;
- the *risk management function*, which provides risk assessment in export-import activities, such as market instability, disruption of logistics chains, or changes in customs tariffs, contributes to effective crisis management; this is consistent with the conclusions of the study [39], where the authors highlight the importance of technological tools for forecasting and reducing risks;
- the *integration of information systems function*, which allows the unification of data from various process participants – government bodies, logistics companies, customs services, banks – into a single information system, increasing the speed and accuracy of decision-making; the integration of information systems, according to the conclusions [41], is a necessary condition for increasing transparency and synchronizing the actions of all export-import stakeholders;
- the *business process efficiency enhancement function* contributes to reducing the costs of administrative management of export-import activities, minimizes the human factor, and promotes the digitization of trade operations. As noted by [8], digitization and automation significantly improve business processes and reduce management costs.

It is essential to note that these technological tracing functions enable the effective management of the flow of goods, finances, and data, thereby contributing to the proper execution of trade operations in accordance with international standards and regulations. In this context, the functions of technological tracing become directly interconnected with management functions, allowing for the creation of a comprehensive system for optimizing and efficiently managing export-import activities.

Conclusions

The conducted research identified the key directions of technological tracing in export-import activities, including supply chain tracing, compliance assurance, financial tracing, and distributed technological platforms. The implementation of digital technologies enhances transparency, data reliability, and security across all stages of international economic operations.

The study examined fundamental principles for the effective functioning of technological tracing systems, which include transparency, data accuracy, automation, integration of information systems, continuous monitoring, regulatory compliance, and feedback mechanisms. Adherence to these principles is essential for efficient organization and coordination of export-import processes.

The functional capabilities of technological tracing were outlined as tools for strategic planning, monitoring and control, regulation and compliance, customs administration optimization, risk management, information system integration, and enhancing business process efficiency. These functions provide comprehensive management of goods, financial flows, and data, thereby contributing to the optimization of foreign trade operations.

The findings underscore the need for further development of technological tracing, with a focus on integrating national systems with international platforms and aligning with European standards. Special attention should be given to improving the regulatory framework, fostering public-private partnerships, and implementing innovative digital solutions in environmental standards, product safety, and intellectual property protection. Such measures will enhance national economic competitiveness and attract investment.

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