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Oliinyk Oleksandr
Candidate of Philosophical Sciences, Associate Professor,
Zaporizhzhia National University
ORCID: https://orcid.org/0000-0003-0511-7681

Олійник О.М.
Запорізький національний університет

AUTOMATION OF TRACEABILITY PROCESSES IN ENSURING SUSTAINABLE DEVELOPMENT OF FOOD INDUSTRY ENTERPRISES

АВТОМАТИЗАЦІЯ ПРОЦЕСІВ ПРОСТЕЖУВАНОСТІ У ЗАБЕЗПЕЧЕННІ СТАЛОГО РОЗВИТКУ ПІДПРИЄМСТВ ХАРЧОВОЇ ПРОМИСЛОВОСТІ

The article examines the automation of traceability processes in the food industry and its impact on supply management, quality control, and regulatory compliance. It demonstrates that the absence of a unified regulatory ecosystem complicates interaction among key stakeholders in the food sector. The study applies an analysis of scientific research, practical cases, and digital tools for integrating Blockchain, Smart contracts, IoT, AI-driven analytics, and end-to-end monitoring. It presents an automated traceability model that covers transport monitoring, digital certification, and governmental oversight. Special attention is given to integration with state digital transformation platforms for automating reporting and monitoring product safety. The research identifies the need to improve the regulatory framework and data exchange standards.

Keywords: *food industry, regulatory authorities, Blockchain, traceability, Smart contract.*

У статті досліджено основні виклики автоматизації простежуваності у харчовій промисловості та її вплив на ефективність постачання, контроль якості і дотримання нормативних вимог. Визначено, що несинхронізовані інформаційні потоки, несумісність облікових систем і фінансово-організаційні труднощі стримують цифровізацію, а відсутність єдиної екосистеми створює інформаційні розриви між виробниками, постачальниками, дистриб'юторами та регуляторами. Використання наукових досліджень, кейс-стаді та аналізу цифрових інструментів дозволило поглибити розуміння інтеграції Blockchain, Smart-контрактів, IoT та ШІ-аналітики для формування єдиної системи управління даними. Запропонована концептуальна модель автоматизованої простежуваності охоплює моніторинг транспортування, автоматизовану сертифікацію, контроль логістики у реальному часі та державний нагляд на основі відкритих даних. Доведено, що Blockchain забезпечує незмінність інформації і прозорість ланцюгів постачання, Smart-контракти прискорюють перевірку відповідності, IoT-сенсори гарантують контроль умов зберігання та транспортування, а штучний інтелект дає змогу прогнозувати ризики і швидко виявляти відхилення. Взаємодія з державними цифровими платформами забезпечує автоматичну звітність і доступ регуляторів до ключових параметрів безпечності, а відкриті дані підсилюють громадський контроль та довіру споживачів. Встановлено, що нормативна база потребує оновлення та уніфікації стандартів обміну даними. Подолання бар'єрів потребує розвитку цифрових компетентностей, стимулів для впровадження цифрових рішень і посилення міжгалузевої інтеграції. Результати дослідження свідчать, що цифрова простежуваність направлена на покращення ефективності харчової галузі, мінімізує шахрайство та зміцнює безпечність продукції, а в довгостроковій перспективі сприяє регуляторній гармонізації й зростанню конкурентоспроможності. Подальші дослідження повинні бути спрямовані на створенні національної системи простежуваності, здатної інтегрувати всі етапи постачання, централізовано перевіряти сертифікати та забезпечувати миттєвий обмін даними на основі Blockchain і штучного інтелекту.

Ключові слова: *харчова промисловість, регуляторні органи, Blockchain, простежуваність, Smart-контракт.*

Formulation of the problem. The automation of traceability processes faces technical, organizational, and economic barriers. Companies utilize various production, logistics, and sales management systems, which are often incompatible, complicating data exchange. Many businesses still rely on manual record-keeping, using paper documentation or spreadsheets, which slows down operations and increases the risk of errors. The implementation of digital solutions requires financial investment, staff training, and internal process restructuring, which is particularly challenging for small and medium-sized enterprises (SMEs). The shortage of qualified IT and data analytics specialists further complicates the adoption of automated systems. Even if a manufacturer upgrades its processes, its suppliers and customers may continue operating with outdated frameworks, preventing end-to-end traceability of products. As a result, the development of digital solutions within the industry remains uneven, and information gaps persist among supply chain stakeholders.

Analysis of recent research and publications. The essence, characteristics, advantages, and drawbacks of modern digital transformation tools have been studied by the following domestic experts: Bortnikova M., Chirkova Yu. [1], Smaglo O. [2], Petko S. [3], Shevchenko N. Yu., Turlakova S. S., Latysheva O. V. [4], Pogrebny V. [5], Povarova N., Melnyk L. [6], Dashko I., Cherep O., Mykhailichenko L. [7], Baranov O. A. [8], Neshchadym L., Tymchuk S. [9], Fedyk T. V. [10], Veretelnyk V. V. [11], Lysiuk T. [12], Mozhova H., Zaika O., Kovalenko A. [13], Honcharuk A., Pidkaminskyi M., and Shliakhovyi O. [14]. However, the development of a conceptual framework for automated business processes in digital traceability within the food industry has not been previously explored.

Highlighting previously unresolved parts of the overall problem. The automation of traceability in the food industry continues to develop actively; however, several unresolved challenges hinder its effective implementation. Despite the availability of digital solutions, the lack of unified data exchange standards among enterprises creates gaps in supply chains, making end-to-end product control more difficult. The accessibility of these technologies for small and medium-sized enterprises (SMEs) remains limited due to the high costs of implementation and the need for business process adaptation. Many companies rely on incompatible systems that do not support automatic data exchange between market participants, leading to fragmented information flows. Manufacturers are forced to operate in an environment where, even with internal automation, they cannot synchronize with suppliers and distributors, reducing the overall efficiency of traceability processes across the entire industry.

Formulation of the purpose of the article. To identify modern technologies for automating the traceability process in the food industry, analyze their impact on supply chain efficiency, and propose approaches for integrating digital solutions that ensure a unified system for product accounting and traceability.

Presentation of the main material. The automation of traceability in the food industry is developing unevenly. Large companies are implementing digital systems, while small and medium-sized producers often remain outside this process. This creates gaps in the information chain, complicating quality and safety control. Increasing regulatory and partner requirements are forcing enterprises to rethink their approaches to data management and exchange. Previously, traceability was limited to storing batch numbers within internal systems. Today, it is essential to ensure end-to-end control from raw materials to the final consumer. Achieving this is impossible without automated solutions that enable fast and error-free tracking of all product movement stages. Manual record-keeping, reliance on paper documentation, and inconsistent data formats across companies create additional challenges. Information may be lost, updates take time, and record-keeping errors lead to inaccuracies. All these factors make the implementation of automated traceability systems not just desirable but a necessary step in the industry's digital transformation.

Modern tools for implementing the concept of digital traceability in the food industry are presented in Tab. 1.

As shown in Tab. 1, the conducted analysis demonstrates a rational approach to selecting technologies for implementing a food traceability system [3]. It encompasses key areas of automation, including process accounting and management, digital identification, quality control, logistics, regulatory compliance, and analytics [6]. A structured approach to tool selection highlights the necessity of ensuring end-to-end traceability and data protection at every stage of the product lifecycle [9]. SAP, MES, and POS systems serve as fundamental management components that structure both production and commercial processes [4, 13]. Their integration creates a unified information environment for product accounting, minimizing the risks of data loss or distortion [3]. The selection of Blockchain as a technology for storing critical records ensures data immutability and transparency, eliminating unauthorized modifications to historical records [1, 2]. Smart contracts add an additional level of automation by enabling automatic compliance verification, blocking uncertified batches, and controlling transportation conditions [1]. The use of IoT sensors and GPS trackers enhances real-time monitoring capabilities, ensuring continuous tracking of temperature, humidity, location, and other critical parameters [5, 8]. These technologies have become an integral part of dynamic risk management in logistics [5]. Regulatory compliance increasingly relies on a centralized monitoring system integrated with government platforms, which allows the automatic generation of reports, the creation of open databases, and the simplification of compliance verification processes [6]. The application of Big Data and AI analytics provides predictive capabilities, enabling the system to automatically detect anomalies, analyze violation trends, and assess risks before products reach the end consumer [7]. Thus, the selection of technologies is based on the principles of end-to-end automation, continuous monitoring, and data integration into a unified system [3]. The combination of Blockchain, IoT, AI, SAP, and government platforms not only enhances

Table 1

Modern tools for implementing the concept of digital traceability in the food industry

№	Category	Tool	Appointment
1	Accounting automation	SAP system	Batch registration, product identification
2		MES system	Production parameter control
3		POS system	Product accounting at retail points
4	Digital identification and traceability	QR codes, RFID tags	Product identification and tracking
5		Blockchain	Data protection, information transparency
6		Smart contracts	Automatic approval or blocking of supplies
7	Quality control and certification	Laboratory systems	Analysis of physicochemical, microbiological indicators
8		Digital certification system	Automatic verification of compliance
9		AI analytics	Automatic detection of non-conformities
10	Logistics and transportation	TMS system	Transport management
11		IoT sensors	Control of temperature, humidity, route
12		GPS trackers	Product location tracking
13	Regulatory control	State monitoring system	Risk analysis, violation tracking
14		Integration with «Diia»	Automatic reporting, open data
15	Analytics and transparency	Big Data	Trend analysis and fraud detection
16		Open API	Information exchange between market participants
17		Platform of public control	Collection of reviews and product ratings

Source: formed by the author based on sources [1–13] food safety control but also improves the efficiency of logistics, production, and regulatory oversight [4, 6, 7]. This approach lays the foundation for the sustainable development of the industry by reducing fraud risks and increasing market trust in food products [6].

Based on the reviewed tools, the concept of automated business processes for digital traceability in the food industry is visualized in Fig. 1–8.

The implementation steps for the business process "Digital identification and certification of raw materials", see Fig. 1.

According to the data in Fig. 1, the process begins with identifying the product's readiness for collection, accompanied by the registration of relevant data in the supplier's digital system. The SAP system automatically generates a unique batch identifier, ensuring traceability at all subsequent stages. Next, laboratory testing is conducted, and the results are recorded in the Blockchain, creating an immutable digital footprint of product safety. A smart contract analyzes the obtained certificates, verifies their compliance with established standards, and either approves or blocks the supply automatically.

In the case of a positive decision, the system generates a shipment confirmation and synchronizes the data with the transportation system, enabling continuous monitoring of transportation conditions.

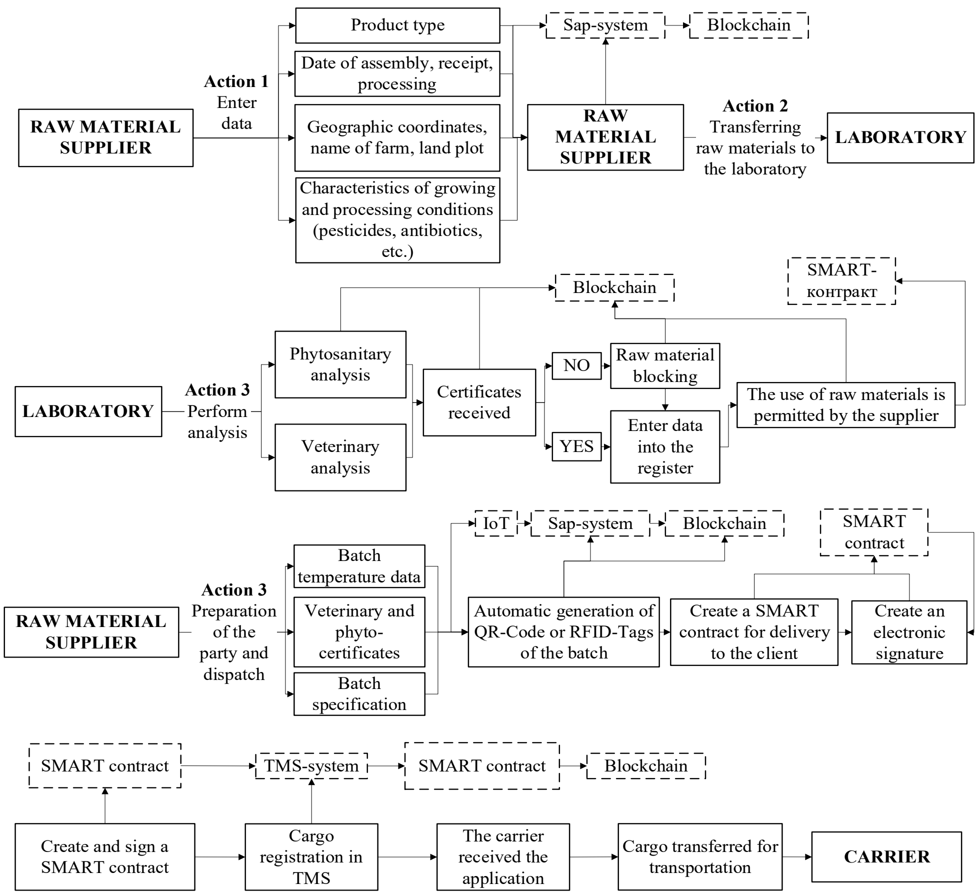

Figure 1. Implementation of the business process "Digital identification and certification of raw materials"

Source: developed by the author himself

The implementation steps for the business process “Digital Verification of Production Processes”, see Fig. 2.

According to the data in Fig. 2, the enterprise receives raw materials using an automated batch scanning system, which instantly verifies their parameters against the Blockchain, ensuring the presence of valid certificates and compliance with transportation conditions. In case of non-compliance, the smart contract automatically halts further processing and initiates an additional inspection. If the data confirms the raw materials' safety, the batch is integrated into the production process through the MES system. All production parameters, including temperature control, processing duration, humidity levels, and other critical indicators, are recorded by IoT sensors, preventing any manipulation or concealment of discrepancies. At each production stage, information is transmitted to the Blockchain, forming a digital trace of the process. Upon completion of product manufacturing, a new unique code is generated, allowing each unit to be tracked individually, thereby ensuring compliance with quality standards.

The implementation steps for the business process “Intelligent quality control and product certification”, see Fig.3.

As shown in Fig. 3, the quality control process involves a multi-level verification system that integrates both laboratory analysis and algorithmic monitoring of regulatory compliance. The laboratory, upon receiving product samples, conducts tests for physicochemical, microbiological, and toxicological indicators, with the results being transmitted to the digital certification system. AI-driven analytics further validate the obtained data against regulatory databases, enabling rapid detection of non-conformities. The smart contract automatically blocks a batch if at least one parameter fails to meet the established criteria, while a valid certificate is instantly registered in the Blockchain and becomes accessible to all supply chain participants.

Implementation steps for the business process “Smart logistics and monitoring”, see Fig. 4.

According to the data in Fig. 4, the transportation process is based on the principle of continuous monitoring of key parameters, achieved through the integration of IoT sensors

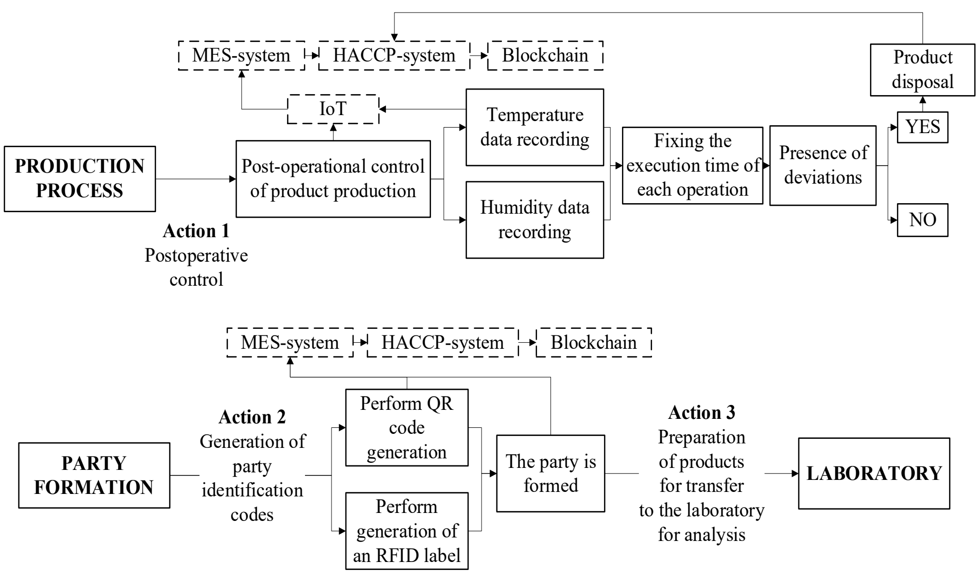

Figure 2. Implementation steps for the business process “Digital verification of production processes”

Source: developed by the author himself

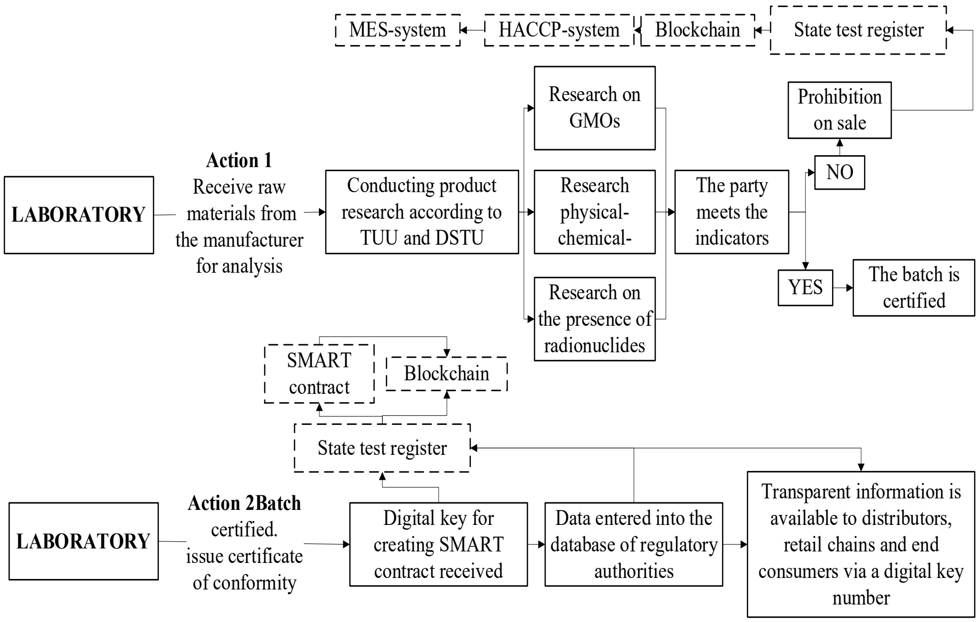

Figure 3. Implementation steps for the business process “Intelligent quality control and product certification”

Source: developed by the author himself

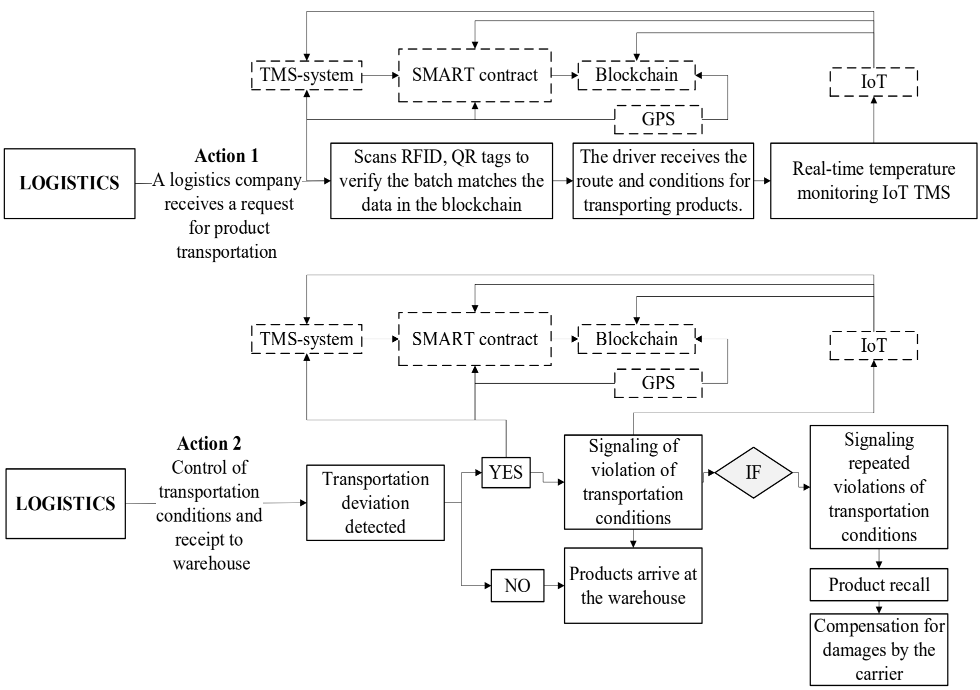

Figure 4. Implementation steps for the business process “Smart logistics and monitoring”

Source: developed by the author himself

and a Blockchain registry. The transfer of goods from the manufacturer to the distributor is accompanied by the scanning of a unique batch identifier, which initiates a verification process to compare declared transportation conditions with actual parameters. In case of discrepancies, the smart contract automatically notifies responsible personnel and halts the distribution process.

Throughout the entire route, GPS trackers record the vehicle's geolocation, while temperature sensors detect any potential breaches of storage conditions.

Any deviation from regulatory parameters is recorded in the Blockchain, ensuring complete transparency in logistics processes and eliminating the risk of product substitution or unethical handling.

Implementation steps for the business process «Digital trade and consumer transparency», see Fig. 5.

As shown in Fig. 5, the arrival of products at retail locations follows the principle of automated compliance verification, enabled through the integration of POS systems with the Blockchain registry. During product acceptance, the unique batch code is scanned, triggering a verification process that reviews all previous traceability stages. If discrepancies are detected, the system automatically blocks the sale and requires an additional inspection. Product stock data is instantly updated in the inventory management system, and each customer has the ability to verify the product's history by scanning a QR code.

This eliminates the risk of selling expired or counterfeit goods, significantly enhancing consumer trust in the brand.

Implementation steps for the business process «Digital consumer quality control and product (manufacturer) reputation management», see Fig. 6.

According to the data in Fig. 6, the final stage of the supply chain ensures interactive engagement between the consumer and the traceability system. Scanning the QR code

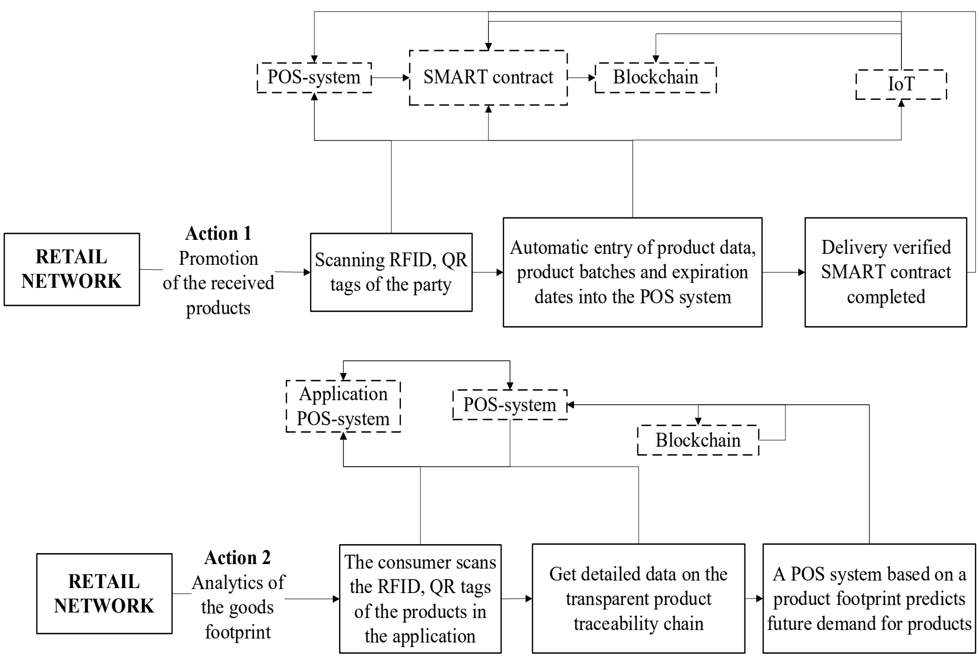

Figure 5. Implementation steps for the business process “Digital trade and consumer transparency”

Source: developed by the author himself

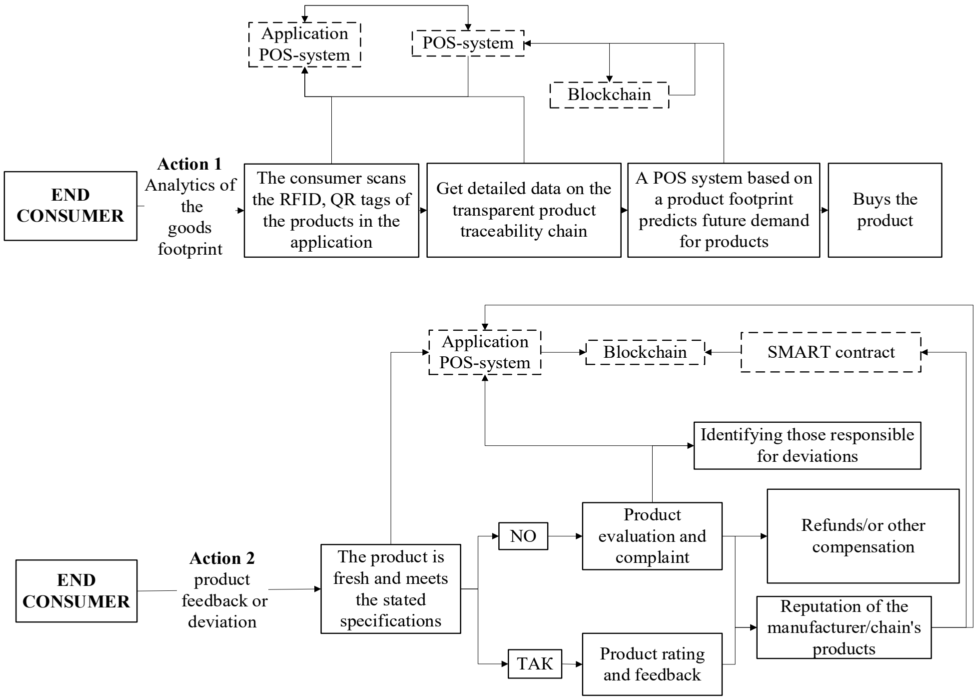

Figure 6. Implementation steps for the business process "Digital consumer quality control and product (manufacturer) reputation management"
Source: developed by the author himself

on the packaging provides immediate access to detailed information about the product's origin, manufacturing conditions, laboratory test results, and transportation history. Additionally, consumers can leave a review, which is recorded as a hashed Blockchain data block, creating an independent quality control system where reviews influence the product's rating. The smart contract automatically analyzes trends in negative reviews, enabling the transparency system to identify potentially problematic batches and initiate additional inspections.

Implementation steps for the business process "Automated regulatory control", see Fig. 7.

According to the data in Fig. 7, the institutional level of control is based on the automated monitoring of the entire traceability system, implemented through AI-driven analytics and Blockchain mechanisms. Government authorities have access to all critical supply chain parameters, enabling them to quickly identify risks, analyze food safety threats, and make proactive decisions regarding product recalls. Smart contracts automatically flag violations, streamlining regulatory processes and allowing for rapid crisis response.

Additionally, integration with governmental regulatory platforms ensures the automatic generation of compliance reports by enterprises, reducing administrative burdens on businesses and minimizing human error in data submission.

Implementation steps for the business process "Transparency verification and risk detection in the supply chain", see Fig. 8.

As shown in Fig. 8, the transparency control system conducts a comprehensive analysis of all records within the supply chain, comparing actual and declared data to detect

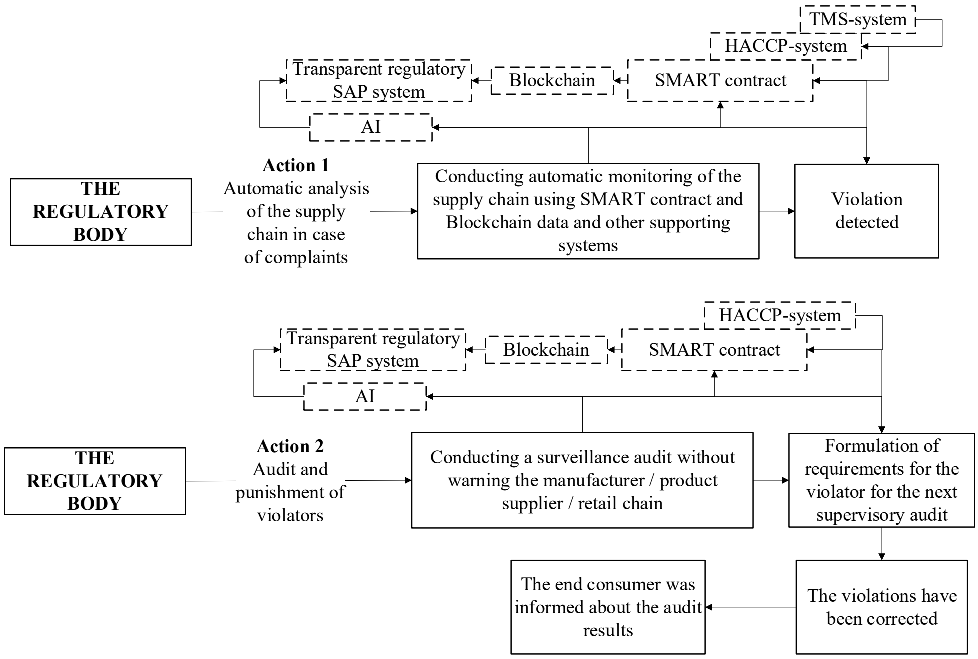

Figure 7. Implementation steps for the business process "Automated regulatory control"
Source: developed by the author himself

anomalies or inconsistencies. AI-powered analytics enable the automatic identification of counterfeit products, document discrepancies, and potential fraud schemes, such as certificate duplication or mismatches in production and delivery dates. Smart contracts instantly block products with a suspicious status, generating inspection requests for the relevant regulatory authorities. Public access to open data ensures maximum transparency and enhances manufacturers' accountability to consumers.

Conclusions. Based on the conducted research, the key challenges associated with the automation of traceability in the food industry have been identified. These include fragmented information flows, difficulties in integrating digital technologies, and the lack of universally accessible data exchange standards for all supply chain participants. A conceptual model of an automated traceability system has been developed, leveraging Blockchain, smart contracts, IoT solutions, and AI analytics to ensure transparency and continuous product control throughout its entire lifecycle. The system's operational algorithm has been outlined, incorporating end-to-end monitoring of transportation and storage conditions, automated certificate verification, and compliance control through smart contracts. Additionally, the advantages of integrating the system with government platforms have been analyzed. This integration facilitates the automatic generation of reports by enterprises, provides regulatory bodies with real-time access to analytical data on violations, and establishes an open database for public monitoring. An assessment has been conducted on the potential impact of digital traceability on reducing fraud risks, improving logistics efficiency, and enhancing regulatory oversight. The analysis results indicate that implementing such a system enables comprehensive food safety control, significantly simplifies interactions between businesses, government authorities, and consumers, and lays the foundation for improving product quality and developing a more effective risk management mechanism in the field of food safety.

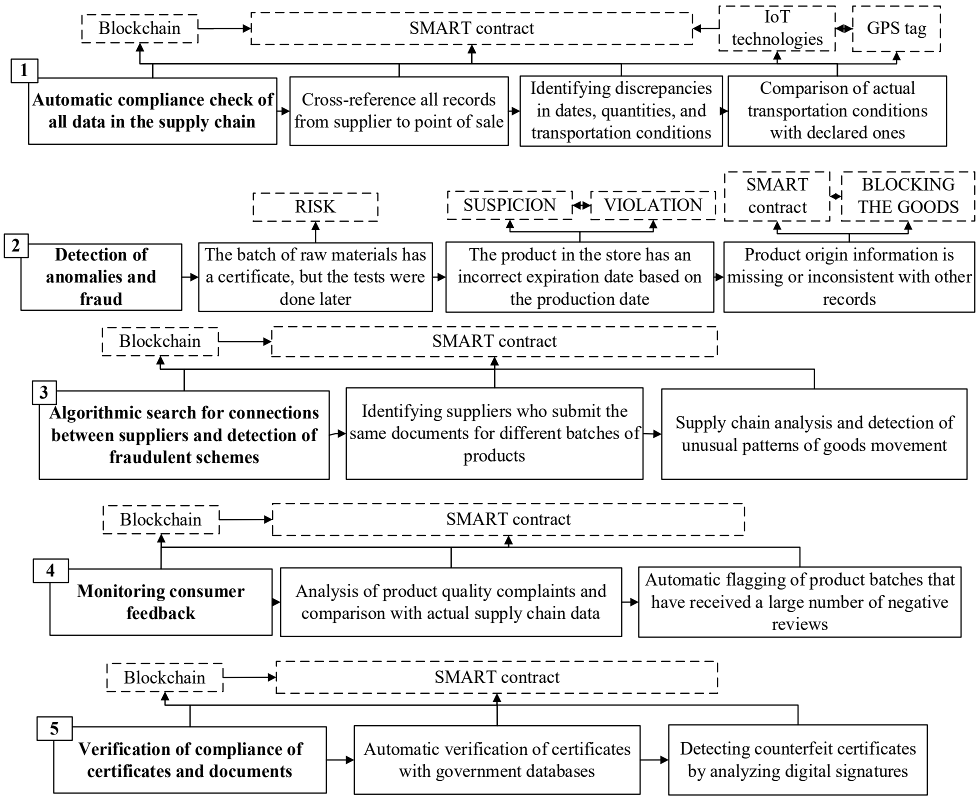

Figure 8. Implementation steps for the business process “Transparency verification and risk detection in the supply chain”

Source: developed by the author himself

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