

Article

Developing a Supply Chain Algorithm for the Delivery of Milk and Dairy Products

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Abstract: This article analyses the theoretical and practical aspects of improving the supply chain for milk and dairy products through the use of digital technologies. The digital architecture model developed as part of this research is designed to integrate the stages of production, processing, logistics and consumption of dairy products into a single digital ecosystem. This model incorporates mechanisms for data collection, analysis, decision-making and monitoring based on Internet of Things (IoT) sensors, Big Data, artificial intelligence (AI), blockchain technology and cloud computing. The architecture ensures data consistency, security and transparency at every stage of the dairy supply chain. The research findings show that a supply system built on digital platforms improves product quality and consumer confidence, reduces logistics costs and optimises the production process.

Keywords: Digital transformation, Internet of Things (IoT) technologies, big data, artificial intelligence (AI), blockchain technology, cloud computing, logistics, data analysis algorithms.

Introduction

The milk and dairy products supply chain plays a vital role in ensuring every country's food security, economic stability and the healthy lifestyles of its population. The efficient operation of this chain not only strengthens trust between producers and consumers, but also ensures product quality control, reduces logistics costs and enables a swift response to market demand.[1]

In recent years, digital technologies, including IoT sensors, Big Data, artificial intelligence (AI), Blockchain and cloud computing, have made it possible to fundamentally transform the supply chain. Using these technologies, data collection, analysis, secure storage and decision-making processes are automated in real time. As a result, all stages from dairy production to delivery to the consumer are becoming a transparent, consistent, and efficient system.[2]

Literature review

In a study by Tian F. on integrating HACCP principles and blockchain technology in the food supply chain, it was demonstrated that a complete traceability system can be established for perishable products such as dairy products. This approach can serve as a methodological basis for designing digital mechanisms in the dairy supply chain [3].

A comprehensive review article by Wolfert S., Ge L., Verdouw C. and Bogaardt M.J. on the application of Big Data technologies in smart agriculture shows that data collected using IoT sensors in the milk production process and real-time data collected using IoT

sensors in the milk production process has been shown to enable a significant reduction in waste throughout the supply chain, and based on these findings, monitoring algorithms specific to the dairy industry can be developed [4].

Casino F., Kanakaris V., Dasaklis T.K., Moschuris S., Stachtiaris S., In an empirical study by Pagoni M. and Rachaniotis N.P. aimed at investigating the effectiveness of implementing blockchain technology in the dairy industry, from the farm stage to the point of consumption, the use of a blockchain-based traceability system is recommended to ensure data integrity and transparency throughout the entire chain from the farm to the point of consumption, and it is appropriate that this approach is directly applied in developing an algorithm for the milk supply chain [5].

The Fourth Industrial Revolution technologies in the dairy industry have been explored by Hassoun A., Ait-kaddour A., Abu-Mahfouz A. et al. - including artificial intelligence, robotics, IoT, Big Data and blockchain - examining the opportunities and challenges in their adoption, the authors have demonstrated the potential of these technologies to fundamentally transform the dairy supply chain at all stages, from the farm to the consumer's table; These conclusions serve as an important theoretical source for defining the working mechanism of our subject [6].

Varavallo G., Caragnano G., A practical study was carried out by Bertone F., Vernetti-Prot L. and Terzo O. on the development and testing of a traceability system based on the energy-efficient Algorand blockchain platform for the dairy supply chain, it was proven that full traceability of the product's origin is ensured for each transaction, with costs not exceeding 0.001 Algo; These results provide practical guidance for research into the implementation of a low-cost and environmentally sustainable digital mechanism in the milk supply chain [7].

Methodology

In this study, several scientific and methodological approaches were used to develop a mechanism and algorithm for improving the milk and dairy products supply chain based on digital technologies. First, an analytical method was employed to analyse existing data on production volumes, logistics costs and consumer demand in Uzbekistan's dairy industry. This process helped to determine the efficiency indicators of the supply chain.[8]

Analysis and results

In the Republic of Uzbekistan, the milk and dairy products industry is recognised as one of the strategic sectors of the economy. According to official data from the Statistics Agency of the Republic of Uzbekistan, In 2023, a total of 11.8 million tonnes of milk were produced in the country, representing a 20.4 per cent increase compared to 2018 [9]. However, this rate of growth is not keeping pace with the level of institutional and technological development in the supply chain.

Translated with. A look at the sector's structure reveals that 94 per cent of milk producers are made up of individual peasant and family farms [10]. This indicator highlights the high level of fragmentation in the supply chain and the need to integrate producers into a single digital ecosystem, while also revealing the industry's institutional weakness. The fact that only 10 per cent of dairy farmers have the status of an official supply chain participant makes the complexity of the situation even more apparent [11].

Translated with The Figure 1. 'Digital Architecture of the Milk and Dairy Products Supply Chain' has been developed based on modern digital technologies, and it envisages managing the entire value chain, from the farm to the consumer, as a single integrated system. The architecture presented in Figure 1 serves to enhance efficiency by ensuring a seamless flow of data, providing transparency, and optimising decision-making processes.

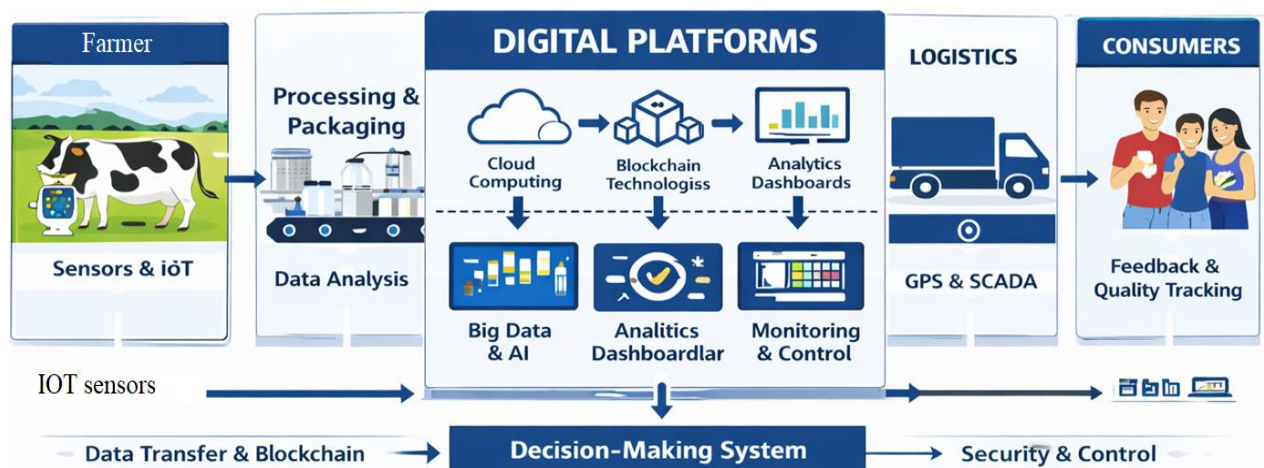


Figure 1. Digital architecture of the milk and dairy products supply chain.

The first stage consists of collecting data in real time at the farm level via sensors and IoT devices. Here, important parameters such as livestock health, milk production volume, feeding status and environmental indicators are monitored automatically. This data undergoes initial processing before being forwarded to subsequent stages. As a result, the reliance on the human factor is reduced, and the accuracy of the data is significantly improved.[12]

The second stage is the production and processing phase, where product quality is monitored and production processes are optimised based on the data collected. In this stage, automated systems are used to process and package the milk and to verify its compliance with standards. Through data analysis, production losses are identified and decisions are made to reduce them.

The third stage is the part where digital platforms play a central role. Here, cloud computing, blockchain technology, big data and artificial intelligence (AI) tools are used. While the cloud infrastructure enables the storage and processing of large volumes of data, blockchain technology ensures the immutability and transparency of that data. Analytical dashboards enable real-time monitoring, providing oversight of every element of the system. This helps to make strategic and operational decisions quickly and accurately.[13]

The fourth stage is a logistics system aimed at optimising the product delivery process. Using GPS and SCADA systems, the movement of vehicles, the condition of the cargo and delivery times are continuously monitored. Through the smart logistics approach, routes are optimised, transport costs are reduced and product quality is maintained. This is particularly important for perishable dairy products.

The final stage. This relates to consumers, where full information about the quality and origin of the final product is provided. Through digital systems, consumers can access information on every stage of the product's journey, from production to delivery. This builds trust and strengthens brand value.

This Figure 2. architecture integrates data transmission, blockchain-based security, decision-making via analytical systems and monitoring mechanisms into a single system. As a result, efficiency, transparency and sustainability in the milk and dairy products supply chain increase[14]. This not only brings economic benefits to producers but also guarantees consumers the delivery of high-quality, safe products.

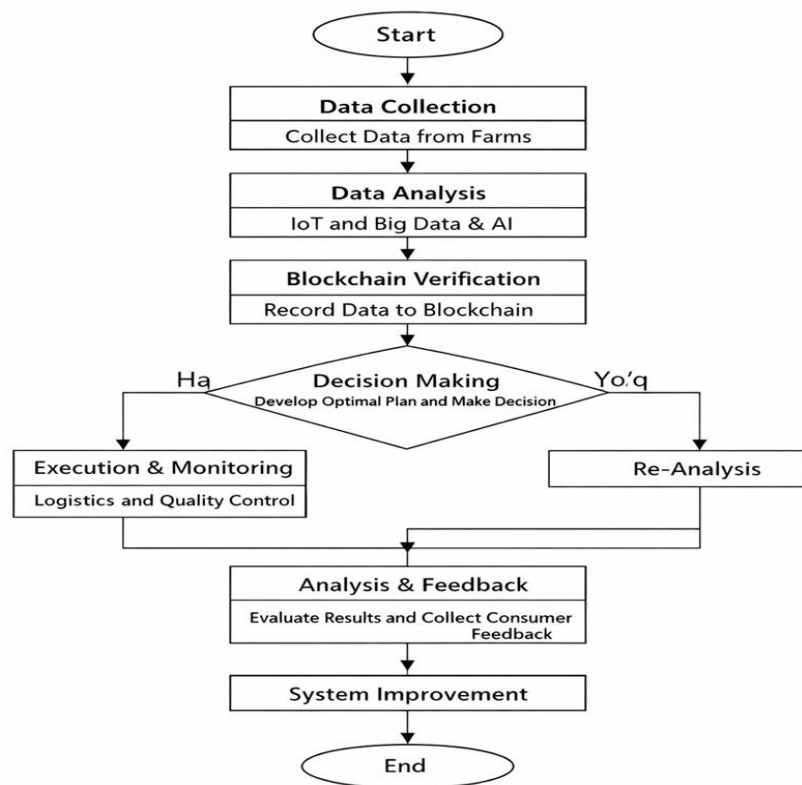


Figure 2. Algorithm for organising the milk and dairy products supply chain based on digital technologies.

Based on this architecture, the algorithm for organising the milk and dairy products supply chain using digital technologies is presented in Figure 2.

The first stage is the “Start” point, where the system is launched and all components begin operating in an integrated manner. In this stage, the initial configurations, the commissioning of sensors and IoT devices, and the overall architecture of the system are activated[15]. This process serves as a crucial foundation for the proper functioning of subsequent stages.

The next stage is Data Collection, in which various data are gathered from farms. This data includes livestock status, milk production indicators, temperature, humidity and other important parameters. Collected in real time via IoT devices, this data is transmitted to the system and subjected to initial filtering. As a result, a reliable and accurate database is created. The third stage is “Data Analysis”, where the data obtained via IoT is analysed in depth using Big Data and artificial intelligence technologies. During the analysis process, trends are identified, problems are forecast, and optimal production metrics are established. This stage provides a scientific basis for decision-making. The fourth stage is the “Blockchain Verification”, which ensures the authenticity and immutability of the data. Every critical operation is recorded on the blockchain system, which drastically reduces the possibility of data falsification. This ensures complete transparency and reliability throughout the supply chain. The next stage is the “Decision-Making” process. Here, an optimal plan is developed based on the analysis results. If the decisions developed by the system are found to be effective (the “Yes” path), they are then implemented. Otherwise (the “No” path), the system proceeds to the re-analysis stage, and the existing data is reviewed once more. This iterative approach serves to increase the accuracy of the decisions.

During the “current monitoring” phase, logistics and quality control are carried out. In this phase, the delivery of products, storage conditions and overall quality indicators

are continuously monitored. Through real-time monitoring, any deviations are promptly identified and the necessary measures are taken.

After that comes the “Analysis and Reflection” stage, where the system’s performance results are evaluated. Based on feedback from users and specialists, the system’s efficiency is determined and any existing shortcomings are identified. This stage serves as an important source of information for the system’s development.

“System improvement” refers to introducing changes to the system based on the analysis and feedback obtained. Algorithms are updated, models are adjusted, and overall operational efficiency is enhanced. This stage ensures the system's continuous development and makes it adaptable to a dynamic environment.

Conclusions and recommendations

The algorithm and digital architecture presented above represent a modern model for the comprehensive management of the milk and dairy products supply chain. It integrates data collection, analysis, blockchain-based verification, decision-making and monitoring processes into a single, seamless cycle. The results show that by applying IoT, Big Data, and artificial intelligence technologies, production efficiency increases, resource utilisation is optimised, and human error is reduced. At the same time, blockchain technology ensures data transparency and integrity, strengthening trust among all participants in the supply chain. The iterative structure of the algorithm allows for the continuous improvement of the system and leads to the following recommendations:

1. It is necessary to widely deploy IoT devices at all stages of the supply chain and integrate them into a single platform. This enables the acquisition of accurate and complete data in real time.
2. The use of artificial intelligence and machine learning algorithms in data processing and analysis processes must be expanded. This will improve forecasting accuracy and help in making optimal decisions.
3. In implementing blockchain technology, it is essential to develop standardised platforms and support them at a national level. This ensures the system operates on a large scale.
4. The quality of products can be maintained and delivery efficiency increased by further improving GPS and smart monitoring systems in logistics processes;
5. It is necessary to organise training for users of the system (farmers, producers and logistics personnel) to enhance their qualifications and develop digital skills. This will ensure the effective use of these technologies.

By implementing these proposals, the efficiency, transparency and sustainability of the milk and dairy products supply chain can be further enhanced.

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