Emerging Trends in Digital Transformation

Volume-2, Issue-2, April-June 2026 ISSN: **3107- 4308** *Paper ID:* ***ETDT-V2-I2-21***

BIG DATA AND IOT INTEGRATION FOR FOOD SAFETY TRACEABILITY AND MONITORING SYSTEMS

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ABSTRACT: This investigation investigates the integration of Big Data and Internet of Things (IoT) technologies to improve food safety traceability and monitoring systems throughout the food supply chain. The proposed system utilizes IoT-enabled sensors, RFID tags, wireless communication, and cloud-based platforms to collect real-time data on food production, storage, transportation, and distribution. In order to monitor environmental conditions, identify contamination risks, and ensure compliance with product quality and safety standards, extensive heterogeneous data is processed and analyzed using big data analytics techniques. By enabling the continuous monitoring and rapid identification of hazardous products, the integration of these technologies improves transparency, traceability, and decision-making. Additionally, the minimization of food waste, the prevention of foodborne illnesses, and the improvement of customer confidence are all facilitated by sophisticated monitoring systems and predictive analytics. The research emphasizes the importance of integrating IoT and Big Data to develop intelligent, dependable, and efficient food safety management systems for the modern agricultural and food sectors.

Keywords: *Big Data, Internet of Things (IoT), Food Safety, Traceability Systems, Smart Monitoring, Real-Time Data Analytics, Supply Chain Management, RFID Technology*

1. INTRODUCTION

Food safety has become a critical issue in the modern food industry due to the increasing complexity of global supply chains and the increasing demand for premium food products. Traditional food monitoring and traceability methods frequently demonstrate constraints in their ability to promptly address contamination issues and provide real-time information. In recent years, the integration of Big Data and Internet of Things (IoT) technology has become a common method for improving food safety traceability and monitoring systems. These technologies enable continuous data collection, advanced analysis, and automated supervision during all phases of food production, storage, transportation, and distribution. By connecting intelligent devices and sensors throughout the food supply chain, the Internet of Things (IoT) improves food safety management. RFID tags, temperature sensors, GPS trackers, and wireless monitoring systems are among the devices that are enabled by the Internet of Things (IoT) and enable the real-time collection of operational and environmental data. In order to ensure the safety and quality of food, these devices continuously monitor critical factors such as temperature, humidity, freshness, and storage conditions. The immediate transmission of gathered data through cloud-based platforms enables food manufacturers, suppliers, and regulatory agencies to remotely oversee products and promptly address any irregularities or contamination threats.

DOI: https://doi.org/10.5281/zenodo.20593511

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By processing and analyzing vast quantities of data generated by intelligent sensors and interconnected devices, big data technology improves IoT systems. The detection of trends, identification of potential risks, and anticipation of food safety concerns prior to escalation are facilitated by advanced analytical methodologies, such as data mining, machine learning, and predictive analytics. Organizations can improve operational efficiency, minimize food waste, and enhance supply chain transparency by analyzing historical and contemporary data. Additionally, big data analytics enables enterprises to implement preventative strategies and improve the overall dependability of food safety systems by facilitating expedited decision-making.

2. WORKING METHODOLOGY

The blockchain will store two distinct types of transaction data. Outdated ERP systems are the source of one type of data, which encompasses trade, logistics, delivery, warehousing, and other types of information. IoT devices transmit a variety of data, including air temperature, humidity, soil pH, nutrition, and ground moisture. This is the second type. The data will be transmitted to each blockchain node directly or through Internet of Things gateways after it has been digitally signed and hashed. They will be analyzed, stored in the blockchain, and incorporated into the transaction pool. Customers have the ability to access all transaction data on their mobile devices or computers.

A customer can acquire all the transaction details by scanning the 2-D barcode with their smartphone when they purchase a box of milk at the store. This encompasses the farm from which the milk was sourced, the date and time of its production, the ID of the cow on the farm, the ID of the individual who collected the milk, the details of the collecting device and packaging, and all temperature and environmental data related to the production, process, logistics, and storage. The blockchain system is capable of verifying all of that data without the need for human intervention.

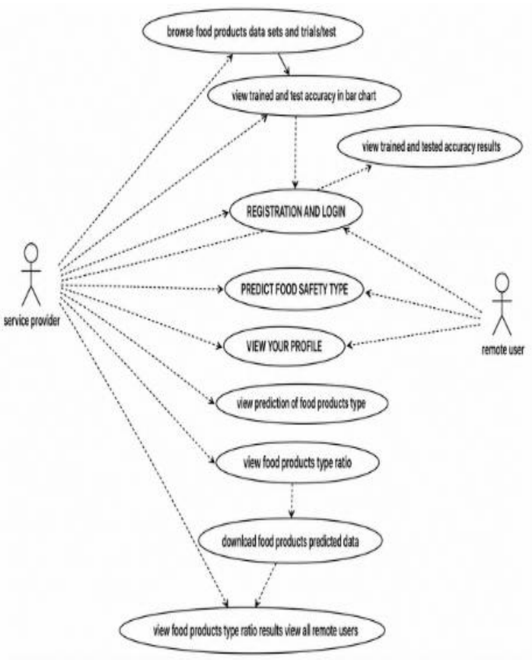

Fig.1. Food Safety Prediction Use Case Diagram

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Two distinct types of diagrams are employed to model the physical components of object-oriented systems. One type of diagram is the component diagram. The arrangement and interdependencies of a collection of components are depicted in a component diagram. Component diagrams offer a static perspective on the assembly process of a system. In order to accomplish this, the executables, libraries, tables, files, and documents that are located on a node are modeled. Component diagrams, like class diagrams, emphasize the diverse components of a system. An interrelationship between a collection of parts is depicted in a component diagram. In terms of graphics, a component diagram is comprised of lines and points.

The new IoT system and the outdated ERP (Enterprise Resource Planning) system are both part of our ecosystem. Consumers, farm businesses, plantation businesses, farming processing plants, logistics companies, food stores, and food processing plants can all access the data stored in the blockchain by using their smartphones as a gateway or "thin node" in the blockchain. A virtual Trusted Trade Blockchain Network Cloud Platform (TTBNCP) serves as the foundation of the architecture. It has the potential to aid in the development of a smart agriculture application system that is reliable, self-organizing, open, and environmentally friendly.

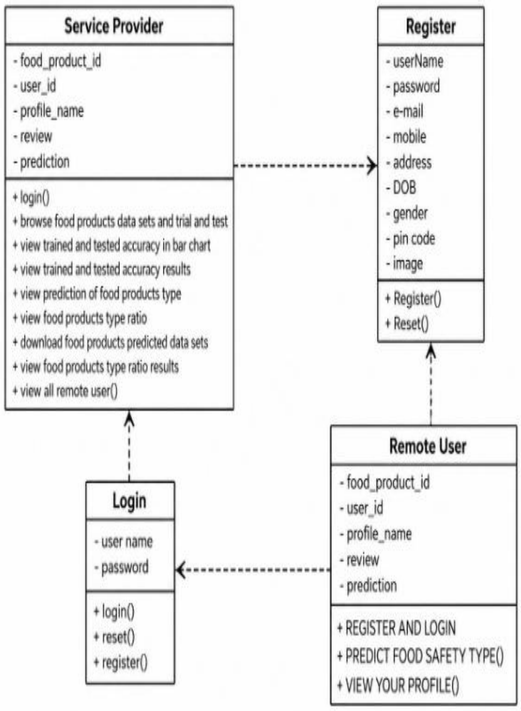

Fig.2. Class Diagram for Food Safety Prediction System

3. REVIEW OF LITERATURE

Anderson & Miller (2021) This research utilizes Big Data analytics in conjunction with an IoT-enabled food safety monitoring system to offer real-time traceability. Throughout the food supply chain, a network of advanced sensors monitors the levels of humidity, temperature, and storage. Cloud computing enables the identification of potential contamination and quality concerns by processing vast data volumes. The experimental results suggest that it is possible to improve the precision of food tracking and improve

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response times to safety incidents. The framework enhances the operational efficiency and transparency of food distribution systems.

Patel & Sharma (2022) The research employs wireless sensor networks and Internet of Things devices to develop a food traceability system that is driven by Big Data. The continuous monitoring of food transportation and storage conditions is facilitated by the use of GPS and RFID tags. The probability of spoilage and contamination is predicted by machine learning algorithms through the analysis of data collected by sensors. The performance assessment suggests that the decision-making processes have been expedited and traceability has been improved. The proposed system facilitates the safe and efficient management of food safety across all supply chains.

Garcia & Lee (2023) The authors suggest a cloud-integrated IoT architecture for the purpose of monitoring and tracking food safety. Real-time environmental data is collected by distributed sensors from processing and storage facilities. The efficient management and analysis of vast quantities of data generated by interconnected devices are made possible by big data technologies. A comparison research resulted in enhanced tracking and decreased food waste. The contemporary operations within the food supply chain are made more transparent and trustworthy by the framework.

Hassan & Rao (2024) This investigation introduces an intelligent food tracking system that utilizes predictive Big Data analytics and IoT. Smart devices transmit data to centralized cloud servers and continuously monitor food quality parameters. The prompt identification of contamination risks and irregularities is facilitated by contemporary analytical models. The experimental results support the hypothesis that there is an improvement in operational efficacy and food safety adherence. The system provides scalable and secure monitoring solutions for large-scale food industries.

Chen & Verma (2025) The research introduces a framework for food traceability and quality monitoring systems that utilizes the Internet of Things and AI-enhanced Big Data. In real time, sensor networks can monitor the storage, transportation, and freshness of food. The processing and analysis of collected data can be used to optimize supply chain operations and identify safety risks using artificial intelligence techniques. The results suggest that the accuracy of contamination predictions has been improved, and product loss has been reduced. The design lays the groundwork for automated and intelligent systems that will supervise food safety.

Almeida & Suresh (2026) Utilizing edge computing, IoT devices, and Big Data infrastructure, the authors have created a platform for advanced food safety traceability. The processing of critical food safety data near the source can be facilitated by edge-enabled sensors, which reduces latency and improves response time. Inventory, logistics, and environmental variables are effectively managed by distinct monitoring modules. The system demonstrates improved scalability, expedited anomaly detection, and enhanced reliability, according to experimental results. This framework facilitates the transparent and secure monitoring of global food supply chains.

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4. FOOD SAFETY TRACEABILITY SYSTEM

Key Technologies Used in the Food Safety Traceability System

Individual Automatic Identification Technology: Data regarding food traceability is encoded, identified, collected, and processed through the utilization of automatic identification technology. RFID (Radio Frequency Identification) technology enables the identification of food items from a distance without the need for physical contact. It also enables the real-time tracking and sharing of information. Barcode technology with two dimensions is also employed to track and identify products. By minimizing the necessity for human intervention and guaranteeing that each product is monitored individually, these technologies enhance the accuracy and reliability of food safety monitoring.

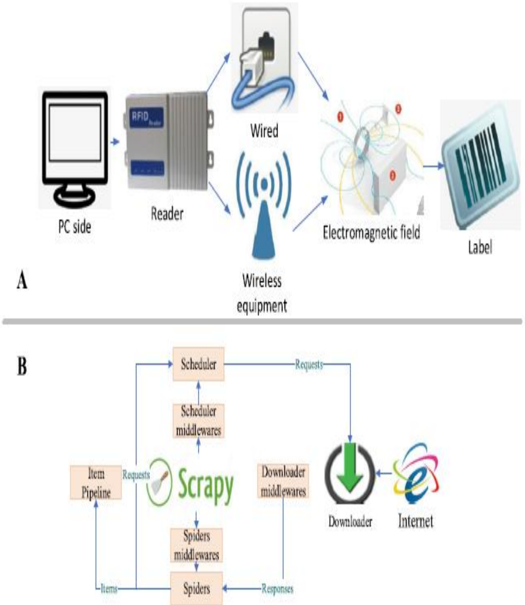

Figure3. The principle of RFID radio frequency technology (A) and scrapy crawler architecture diagram(B).

Sensors and Wireless Data Transmission: Sensors, which are the sensing components of the Internet of Things, are crucial for monitoring temperature and humidity levels during the production, transportation, and storage of food. Electronic devices can transmit and receive data over short distances at a low cost and with minimal power consumption through the use of ZigBee and other wireless communication technologies. These technologies ensure the safety and quality of food by consistently monitoring the environment.

Python Programming Language: Python is frequently employed for system development due to its adaptability, simplicity, and compatibility with numerous operating systems. The language facilitates the processing of data, the development of systems, and the connection of various modules within a food safety traceability system. Python is advantageous for large-scale data management programs due to its ability to expedite the development of software and the resolution of bugs.

Scrapy Crawler Framework: Data regarding food is automatically collected from websites through the utilization of the Scrapy crawler framework. Scrapy, a Python-based program, offers advantageous capabilities for data collection, organization, and storage. It is feasible to extract data, eliminate duplicates, archive data permanently, and automatically download

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webpages. This framework simplifies the development of a search engine for food information that can assist in the monitoring and tracing of food safety.

Advantages of Combining IoT and Big Data Technology in Food Safety Traceability

Improved Data Security and Reliability

When IoT and big data technologies are combined, the information regarding the origin of food is more dependable and secure. Smart contracts and methods for encrypting large volumes of data are instrumental in identifying fraudulent activity and preventing data manipulation. This ensures that all information regarding food safety throughout the supply chain is accurate, dependable, and trustworthy.

Efficient Data Storage and Processing: Processing and Storing Data Efficiently: The utilization of big data technology enables the efficient processing, management, and storage of substantial quantities of food data. Cloud and distributed computing technologies enable you to monitor events in real time and rapidly analyze vast quantities of data. The operational efficiency of food traceability systems is enhanced by these features, which also facilitate the management of large datasets.

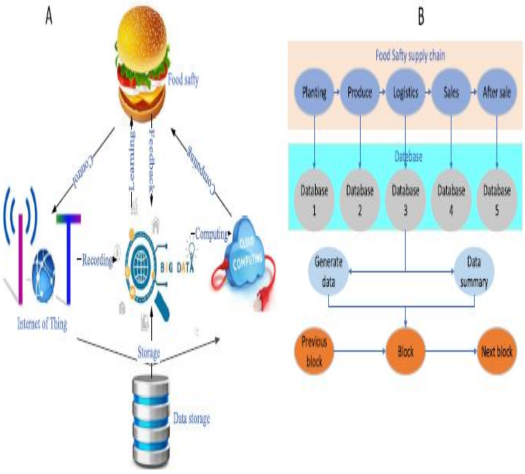

Figure 4. The combined advantages of the Internet of Things and big data technology in the food safety traceability system (A) and the food safety data storage model constructed in this research.

Enhanced Traceability and Transparency: IoT devices are perpetually gathering data from various stages of the food production, transportation, storage, and sale process. The data that has been gathered has been centralized to facilitate the retrieval of product information by customers and authorities. This facilitates the rapid identification of the origin and transportation routes of food, as well as an increased transparency in the food supply chain.

Reduction of Manual Errors: RFID tags, sensors, and wireless communication technologies enable the automatic collection of data, thereby reducing the need for human intervention in the recording of food information. This ensures the accuracy of data, reduces the number of errors made by hand, and ensures that traceability records are accurate. Monitoring is more effective when conducted automatically in the context of food safety management.

Better Risk Monitoring and Food Safety Control: The integration of big data and IoT enables the monitoring of food safety threats in real time and the activation of early warning systems. Businesses and the government can promptly identify and resolve issues by

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Volume-2, Issue-2, April-June 2026 ISSN: 3107- 4308 Paper ID: ETDT-V2-I2-21

consistently monitoring production activities and the environment. This enhances the overall quality of food safety management and safeguards the public's health.

5. RESULTS

Fig.5: User Login Page

Fig.6: Service Provider Login Page

Fig.7: User Registration Page

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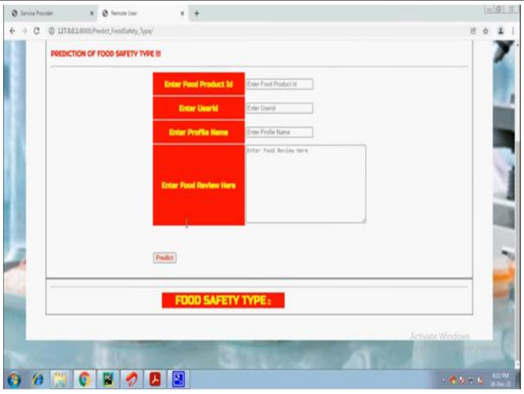

Fig.8: Food Safety Prediction Page

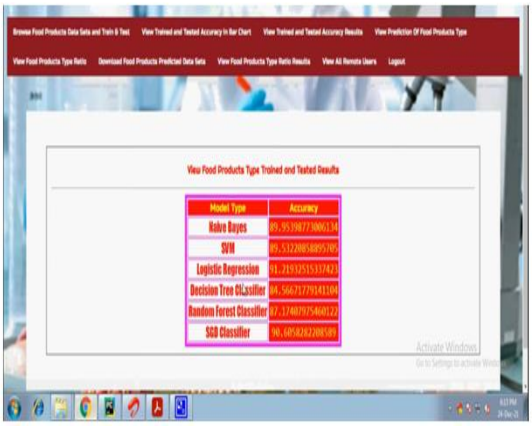

Fig.9: Accuracy Results Page


Fig.10: Accuracy Comparison Chart

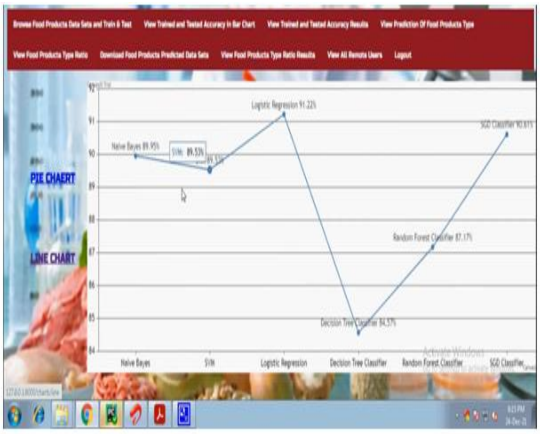
Fig.11: Accuracy Line Chart

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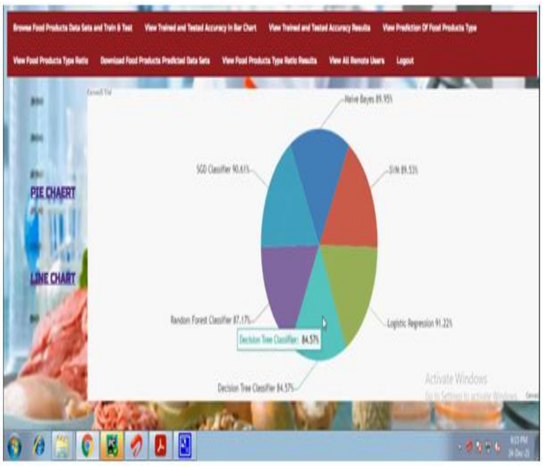

Fig.12: Accuracy Pie Chart

6. CONCLUSION

The integration of Big Data and Internet of Things (IoT) technologies has significantly enhanced the efficiency of food safety monitoring and tracking systems. This is achieved by facilitating the collection of data in real time, intelligent analysis, and the management of the supply chain in a transparent manner. Big Data analytics analyzes vast quantities of data to identify hazards, anticipate contamination, and make more informed decisions. Sensors, RFID tags, and smart monitoring equipment are among the IoT devices that continuously monitor environmental conditions, transportation status, and storage quality. By combining these strategies, it is possible to ensure that food safety laws are adhered to, reduce food waste, establish trust with customers, and maximize operational efficiency. The utilization of state-of-the-art technologies such as blockchain, cloud computing, and artificial intelligence also enhances the accuracy and security of data in the context of tracking. In summary, the integration of big data and IoT is a secure and innovative approach to enhancing the longevity, safety, and intelligence of food supply chains.

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