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Conceptual Framework for Halal Supply Chain Traceability and Food Safety in Indonesia Based on Blockchain Technology and Internet of Things to Support Sustainable Development †

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Abstract: Halal supply chain traceability and food safety are critical issues in the food industry, especially in Indonesia, which has the largest Muslim population in the world. This study aims to develop a halal supply chain traceability and food safety model based on Blockchain and Internet of Things (IoT) that can improve transparency, efficiency, consumer trust in food products, and support sustainable development. This study proposes a conceptual framework for a halal supply chain traceability and food safety model based on Blockchain and IoT technologies. This model is expected to help Indonesia address issues related to halal assurance and food safety.

Keywords: halal supply chain; food safety; traceability; blockchain; internet of things

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1. Introduction

The food industry is a crucial sector for the economy of Indonesia, the country with the largest Muslim population in the world. The need for halal food products whose safety is guaranteed continues to increase along with consumer awareness of the importance of halal food [1] and food safety [2]. However, the complexity of the food supply chain, which involves various stakeholders ranging from farmers, producers, and distributors to final consumers, creates challenges in ensuring the halal and safety of products that reach consumers.

Traceability in HSC and food safety are key elements that ensure that the products consumed comply with halal standards and are free from dangerous contamination [3]. However, conventional traceability systems are often ineffective in providing accurate and transparent information because they are susceptible to human error, data falsification, and lack integration between supply chain stages [4].

In this context, Blockchain technology and the Internet of Things (IoT) offer innovative solutions to overcome the limitations of traditional traceability systems. Blockchain is a statistical configuration that connects information access in the form of blocks in a ledger chain that is distributed automatically and is specifically supported by several hosts [5]. Blockchain, with its decentralized nature and immutability, can ensure that every transaction and product movement in a supply chain is recorded permanently and cannot be changed [6]. IoT technology can be used to monitor environmental conditions and product quality in real time using sensors connected to the internet [7]. In traceability systems, the

use of IoT is related to the existence of a sensor system. The sensor automatically detects the product code and stores the recorded data in a protected database [8]. The integration of these two technologies can create a traceability system that is more transparent, efficient, and reliable and supports sustainable development [9].

This research aims to develop a model for HSC traceability and food safety based on Blockchain and IoT technologies in Indonesia. The proposed model is expected to increase the transparency of information throughout the supply chain, reduce contamination risk, support sustainable development, and increase consumer confidence in Halal food products.

A comprehensive approach involving literature reviews, interviews with experts, and case studies on food companies in Indonesia is expected to provide in-depth insights and applicable solutions to overcome challenges in halal supply chain traceability and food safety. Thus, this research not only contributes to the development of science but also has a positive impact on the halal food industry in Indonesia.

2. Methodology

This research builds a conceptual framework for a Halal Supply Chain (HSC) traceability model and food safety based on Blockchain technology and the Internet of Things (IoT) in Indonesia. The conceptual framework is a general description of the research to be conducted, where the procedures and research objectives are described [10]. The methodology used in this research includes several systematic stages to ensure the accuracy and validity of the research results. According to [11], the following are the stages of the methodology used:

2.1. Literature Review

The initial step in this research was to conduct an in-depth literature review to understand the concept of HSC traceability and food safety, as well as Blockchain and IoT technology. The literature review includes the following sections:

- Identification and analysis of previous research related to food supply chain traceability, especially in the context of halal and food safety.
- Implementing blockchain and Internet of Things (IoT) technologies in various industries, including the benefits and challenges faced.
- Collection of data and information regarding halal standards and food safety in Indonesia.

2.2. Identify Key Variables

Based on a literature review and consultation with experts, key variables relevant to halal supply chain traceability and food safety were identified. These variables include the following:

- Input variables: raw material source, environmental conditions, halal certification, and production data.
- Process variables: Processing, storage, and distribution procedures.
- Output variables: Final product quality, halal information, and food safety.

2.3. Build a Conceptual Framework

The conceptual framework for this research outlines the structure and components of the model for halal supply chain traceability and food safety based on Blockchain and Internet of Things (IoT) technologies. This framework identifies key variables, their relationships, and theoretical underpinnings that guide the development and implementation of the model. The conceptual framework is divided into several core components, each representing a critical aspect of the research:

- Halal Supply Chain and Food Safety Context

Definition and Importance: Understanding the principles of HSC and the critical need for food safety within the context of a predominantly Muslim population in Indonesia.

Challenges: Identifying challenges such as lack of transparency, contamination risk, and inefficiencies in current halal supply chains.

- Blockchain Technology

Immutable Ledger: Use blockchain's decentralized and immutable ledger to record every transaction and movement of goods within the supply chain.

Smart Contracts: Smart contracts are implemented to automate compliance checks and certifications for halal standards.

Transparency and Trust: Enhance transparency and trust among stakeholders by providing a tamper-proof record of the entire supply chain process.

- Internet of Things (IoT)

Real-Time Monitoring: IoT sensors are deployed to monitor environmental conditions (e.g., temperature, humidity) and track the location of products in real time.

Data collection: We collected data on product conditions throughout the supply chain to ensure compliance with halal and safety standards.

Alerts and Notifications: Use IoT to generate real-time alerts for deviations from predefined standards, ensuring timely corrective actions.

- Integration of Blockchain and IoT

Data Integration: Integrating data from IoT sensors with Blockchain to create a comprehensive and immutable record of the supply chain.

Enhanced Traceability: Providing end-to-end traceability of products from farm to fork, ensuring that all halal and safety standards are consistently met.

Stakeholder Collaboration: Facilitating better collaboration among all stakeholders (producers, processors, distributors, retailers, and consumers) through shared access to reliable data.

- Expected Outcomes

Improved Transparency: Achieving higher transparency in the halal supply chain that builds consumer trust and meets regulatory requirements.

Increased Efficiency: Streamlining supply chain operations through automation and real-time monitoring will lead to cost savings and reduced waste.

Enhanced Food Safety: Ensuring that food products meet safety standards at every stage of the supply chain and reducing the risk of contamination and recalls.

Consumer Confidence: This step boosts consumer confidence by providing verifiable information about the halal status and safety of food products.

Figure 1 shows the stages of the methodology used in this study.

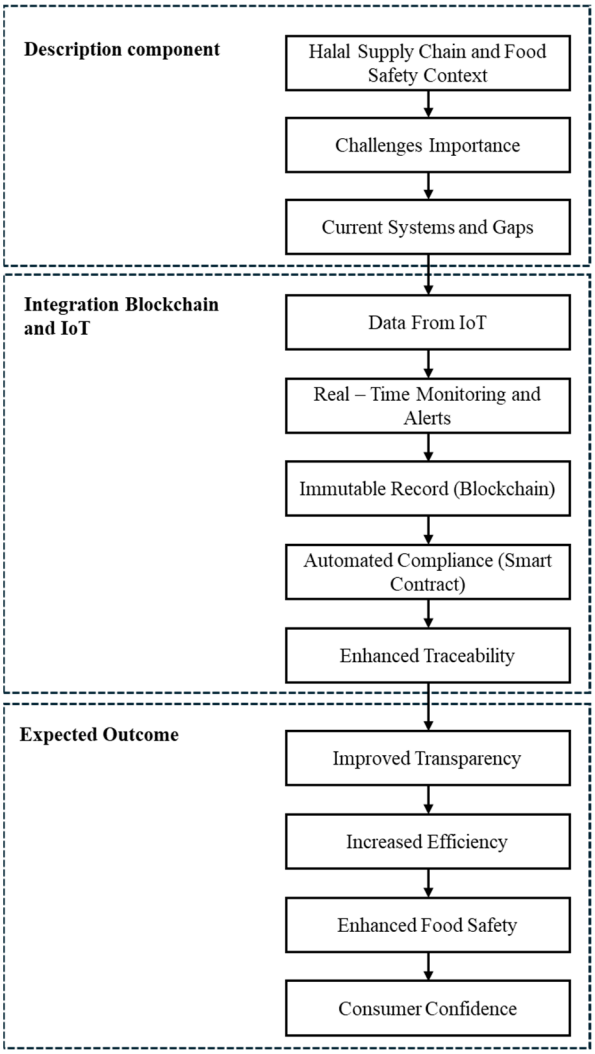

Figure 1. Conceptual Framework Diagram.

3. Analysis and Result

The conceptual framework serves as a blueprint for developing robust and comprehensive halal supply chain traceability and food safety models using blockchain and IoT technologies [12]. This research seeks to offer a sustainable solution by building on the strengths of advanced technologies and addressing the shortcomings of existing systems. The ultimate goal is to guarantee halal integrity, strengthen food safety measures, and increase consumer confidence in Indonesia's food distribution system.

Traceability in the halal supply chain and food safety is a complex but crucial process to ensure the integrity and quality of food products. In Indonesia, which has the largest Muslim population in the world, the need for an effective traceability system is increasing. People who play a role in the food supply chain, as shown in Figure 2, include farmers, suppliers, the food industry, retailers, consumers, and government agents. Blockchain technology and the Internet of Things (IoT) offer innovative and efficient solutions to overcome challenges in ensuring halal and food safety. The traceability model proposed in this research integrates these two technologies to create a transparent, accurate, and trustworthy system.

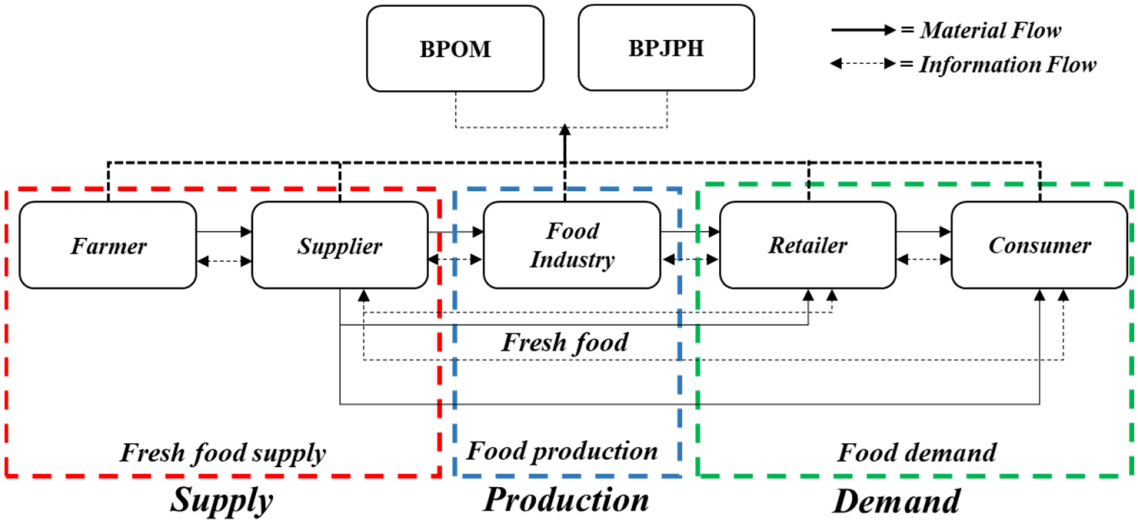

Figure 2. Food supply chain in Indonesia.

3.1. Model Components

Blockchain- and Internet-of-Things-based halal supply chain and food safety traceability models consist of several main components that are integrated with each other:

- Blockchain

Blockchain technology enables the permanent and irreversible recording of every transaction and product movement in a supply chain. Each entity in the supply chain has the same copy of the data, thereby increasing transparency [13].

Smart contracts are used to automate halal and food safety verification. When certain conditions are met, smart contracts automatically execute the necessary actions, such as recording halal certification or sending notifications to relevant parties.

- Internet of Things (IoT)

IoT sensors are installed at various points in the supply chain to monitor environmental conditions such as temperature, humidity, and cleanliness. The data collected by these sensors are sent in real time to the Blockchain platform [14].

IoTs enable real-time tracking of product locations throughout production, storage, and distribution processes. This ensures that each product can trace its origin and journey.

- Blockchain and IoT integration

Data collected from IoT sensors are stored on Blockchain, creating a transparent and immutable record. This integration ensures that information related to halal and food safety can be easily verified by all interested parties [15].

This system is equipped with an alert and notification mechanism to notify relevant parties in case of a violation of halal or food safety standards. For example, if the storage temperature exceeds the specified limit, a notification is sent to the warehouse manager.

3.2. Traceability Workflow

The workflow of the halal supply chain traceability and food safety model based on blockchain and IoT technology is shown in Figure 3:

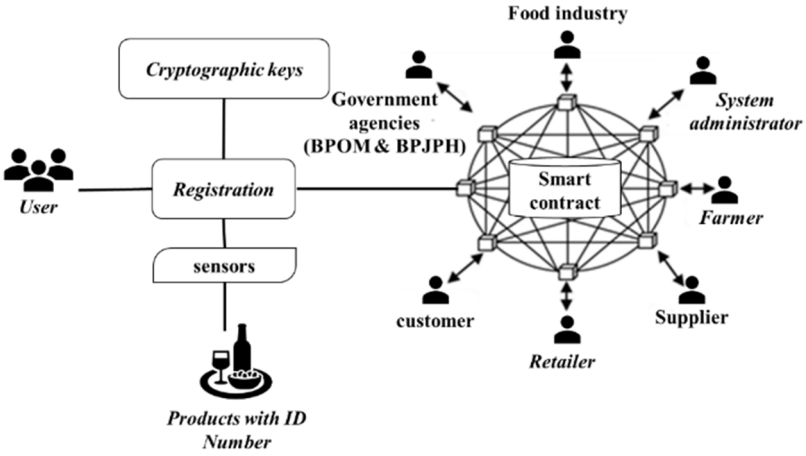

Figure 3. Traceability model for halal supply chain and food safety.

3.2.1. Farmer

Farmers keep records and ensure that the raw materials used are halal and safe. Information about these raw materials is recorded on Blockchain.

3.2.2. Supplier

Suppliers buy products from farmers and record them to ensure that the raw materials used are halal and safe. Information about these raw materials is recorded on Blockchain.

3.2.3. Manufacturer

IoT sensors are installed in production areas to monitor environmental conditions and ensure that the production process meets halal and food safety standards.

Throughout the processing stage, IoT sensors carry out ongoing monitoring of product conditions. Information from these sensors is transmitted directly to the Blockchain in real-time, generating a tamper-evident log. Each processing stage must adhere to predetermined standards in order for the product to progress to the next stage.

3.2.4. Retailer

Products that have been processed are then packaged and labelled with a QR code linked to the Blockchain. Monitoring storage conditions for products in distribution vehicles involves the use of IoT sensors to track temperature and humidity levels during delivery. This data are also transmitted to the Blockchain.

In storage warehouses, IoT sensors continuously monitor environmental conditions to ensure products remain in good condition. Any meaningful change in conditions will trigger a notification to the warehouse manager. Blockchain records every time a product is moved or accessed, creating a clear record of who accessed the product and when.

3.2.5. Consumer

Consumers can scan the QR code on the product to see the complete history of the product, including the origin of raw materials, processing, storage conditions and distribution. This information increases consumer confidence in the halal and safety of the products they buy.

3.2.6. BPOM

BPOM is the institution responsible for monitoring food safety, quality, and nutrition in Indonesia [16]. In Blockchain and IoT based traceability models, BPOM can play the following roles:

- Real-Time Monitoring: With IoT integration, BPOM can monitor the storage and transportation conditions of food products in real time, ensuring that the products meet food safety standards.
- Data Transparency: Data stored on Blockchain gives BPOM transparent and unalterable access to the entire product history, simplifying the inspection and audit process.
- Food Safety Standards: BPOM can establish and update food safety standards that must be followed by all parties in the supply chain and use smart contracts on the Blockchain to automate compliance with these standards.
- Taking Quick Action: If a violation of security standards is detected via IoT sensors, BPOM can take immediate action to withdraw the product from the market, preventing potential risks to consumers.
- Increased Awareness: BPOM can use data from the Blockchain system to educate producers and consumers about the importance of food safety and ways to ensure safe and quality products.

3.2.7. BPJPH

The BPJPH is the institution responsible for implementing halal product guarantees in Indonesia [17]. In this model, BPJPH can play the following roles:

- Certification Process: BPJPH can integrate halal certification into blockchain technology, ensuring that all certification data are transparent and verifiable. This includes verification of raw materials, production processes, and finished products.
- Continuous Monitoring: With IoT, BPJPH can monitor production processes continuously to ensure that there is no contamination or violation of halal standards.
- Data Transparency: Blockchain provides a complete and immutable record for all activities in the supply chain, making it easier for BPJPH to conduct audits and verifications.
- Smart Contracts: The use of smart contracts can automate routine verification and audits, reducing administrative burdens and increasing efficiency.
- Inter-Institutional Collaboration: BPJPH can collaborate with BPOM and other institutions through the Blockchain platform to ensure that all aspects of halal and food safety are met.
- Increased Transparency: By providing consumers with access to the halal status of products via QR codes, BPJPH increases transparency and consumer confidence in halal products on the market.

4. Discussion

The implementation of Blockchain and Internet of Things (IoT) technology in halal supply chain traceability and food safety models has various significant impacts that can increase efficiency, transparency, and trust in the supply chain. This technology enables tighter supervision and automation of the verification process, which is crucial for ensuring the halal and safety of food products in Indonesia. In accordance with the literature [18–20], the positive impacts or benefits of implementing blockchain and IoT technology in halal supply chain traceability and food safety models include the following:

1. Transparency and Accountability
    - Immutable Record: The blockchain stores all transaction data in the supply chain in a decentralized, immutable ledger. This allows all parties to trace the origin and journey of the product transparently.
    - Easy Access to Information: Customers can access product information via a quick response bar code, providing greater confidence in product height and safety.

2. Operational Efficiency
    - Verification Process Automation: Smart contracts on Blockchain can automate halal and food safety verification, thereby reducing the need for time-consuming and costly manual verification.
    - Cost Reduction: With automation and a reduction of human errors, operational costs can be reduced significantly.
3. Real-Time Monitoring
    - IoT sensors: IoT enables real-time monitoring of environmental conditions, such as temperature and humidity, which are important for ensuring products remain in optimal condition during storage and transportation.
    - Automatic Notification: This system can provide automatic notification if a violation of halal or food safety standards is detected, enabling quick action to correct the problem.
4. Improved Food Safety
    - Early Detection of Contamination: With real-time monitoring by IoT sensors, potential contamination or violations of food safety standards can be detected early and addressed.
    - Reduction of Recall Risk: With accurate and transparent information, the risk of product recalls can be reduced because problems can be identified and resolved before the product reaches consumers.
5. Consumer Confidence
    - Verified Information: Consumers can independently verify halal and food safety claims, thereby increasing their confidence in the products they purchase.
    - Clear Labeling: Products with clear and transparent information about their origins and production processes tend to be more trusted by consumers.
6. Sustainable Development Support
    - Energy and resource efficiency: This technology helps optimize the use of energy and resources in production and distribution processes, thereby supporting sustainable practices.
    - Carbon Emission Reduction: By improving operational efficiency and reducing waste, this technology can contribute to the reduction of carbon emissions, thus supporting sustainable development goals (SDGs).

Apart from having a positive impact, the implementation of Blockchain technology and the Internet of Things also has potential impacts and challenges, including the following:

1. Implementation Complexity
    - Initial implementation costs: Although this technology can reduce costs in the long term, the initial costs associated with installing IoT sensors and developing a Blockchain system can be high.
    - Infrastructure Requirements: Implementation of this technology requires adequate digital infrastructure, which may not be available in all regions.
2. Data Security
    - Need for Cyber Security: Although Blockchain offers high security, cyberattacks are risk factors that must be anticipated and managed properly.
    - Data privacy: The protection of personal and sensitive data must be ensured to prevent the misuse of information.
3. Adjusting Regulations and Policies

- New regulatory framework: The use of this innovative technology may require regulatory and policy updates to ensure that all legal and ethical aspects are met.
- Standardization: Clear and uniform standards must be established to ensure the interoperability of Blockchain and IoT systems across supply chains.

Currently, research on traceability models that combine halal supply chain traceability and food safety models is lacking. The research that has been conducted still discusses the concept of the HSC traceability model alone [21–23] and the food safety traceability model alone [24–26], especially in Indonesia. [21] presents research on halal traceability using blockchain. [22] investigates HSC management, halal certification, and traceability on SMEs performance. [23] measures the integrity and legitimacy of evidence of halal product traceability in Indonesia. Meanwhile, [24] designed a smart traceability model for food safety in rice products. [25] discussed food safety traceability in meat products. [26] conducted a food safety traceability study for SME food products. Therefore, this study attempts to present a complete conceptual framework for the halal supply chain traceability and food safety model based on blockchain technology and the internet of things in Indonesia.

5. Conclusions

The implementation of Blockchain and IoT technology in the halal supply chain traceability and food safety model offers significant benefits, including increased transparency, operational efficiency, consumer trust, and sustainable development support. However, implementation faces challenges such as high initial costs and the need for adequate infrastructure. With proper handling, this technology can effect major positive changes in ensuring halal and food safety in Indonesia, improving the quality of life and consumer trust in food products, and supporting sustainable development for companies.

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