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Blockchain-Driven Halal Supply Chains: Enhancing Transparency and Efficiency While Ensuring Shariah Adherence

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Abstract: Halal-certified products are in high demand globally, but traditional supply chains face challenges like inefficiency, lack of transparency, and low trust among stakeholders. This study proposes a Shariah-compliant blockchain-based Halal supply chain management system to address these issues. By using Hyperledger Fabric, the system ensures traceability and trust through data-smart auditing, creating a decentralized, immutable ledger with a permission blockchain. The system automates compliance checks via smart contracts and integrates with Shariah boards for certification validation. It also incorporates QR code-based product authentication and off-chain storage for scalability. Periodic audits maintain system integrity, and end-to-end monitoring provides full visibility, ensuring Shariah compliance at every stage. This solution offers a modular, scalable, and transparent approach to Halal supply chains, improving efficiency, privacy, and trust while addressing the shortcomings of traditional methods.

Keywords: *Blockchain, Halal Supply Chain, Shariah Compliance, Smart Contracts, Data Auditing.*

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I. INTRODUCTION

Blockchain technology is one of the most revolutionary innovations of 21st century that can overcome many of the long term challenges of supply chain industry. The blockchain technology characteristics, such as immutability, decentralization, and transparency, have positioned blockchain technology to be particularly beneficial for enhancement of supply chain operations by tracking and reducing inefficiencies [1]. The mainstream adoption of such technologies has been reported in sectors such as finance, healthcare, and logistics [8], [9], but their application for Halal supply chain management is still an emerging field.

So, halal supply chain has some special features differentiating it from a normal supply chain. Such compliance with the precepts of Shariah is throughout the product lifecycle — that is, from the raw materials to the manufacturing, distribution and retail. The monitoring of Halal products becomes crucial as the certification processes must comply with Islamic concepts [9],[11]. However, the existing systems are inefficient, non-transparent, and vulnerable to data tampering which ultimately leads to a lack of trust among the parties and hinders compliance [12]. In recent years, the global demand for Halal-certified products has increased at a rapid pace, largely due to the increasing awareness of consumers and a gradual increase in the Muslim population. This trend has not helped the need for sound systems that can provide operational efficiency and ensure trust and compliance throughout the supply chain [8]. The traditional systems with manual processes, with disparate data and without proper auditing, are unable to cope with such requirements and are unable to maintain the state of compliance in a certified Supply Chain leading to a loss of stakeholder trust [5]. Blockchain technology has the potential to overcome these challenges. By providing decentralized and immutable ledger

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[7], blockchain ensures real-time traceability, transparency and trust across supply chain participants. Smart contracts — self-executing programs on blockchain platforms — can streamline the process of verifying compliance by automating it, reducing human intervention and the potential for error. Furthermore, the integration of blockchain with other digital technologies (e.g., Internet of Things (IoT) and Artificial Intelligence (AI)) will enable greater real-time visibility, predictive modelling and enhanced decision-making so that supply chain processes are made more robust [12].

And there are great possibilities, but integrating the blockchain to Halal supply chains is not easy at all. The majority of previous research studies focus on general usage of blockchain, especially its possibility of providing trust and increasing efficiency [4]. However, such studies neglect important features of Halal supply chains such as Shariah compliance and strong data auditing demands [8]. Moreover, scalability, data privacy, and compliance with current global certification standards still serve as major inhibitors of mass adoption [16]. In this study, a structured framework for blockchain-based Halal supply chain management is proposed to fill these gap areas by embedding Shariah compliance Mechanism with enhanced data auditing functions on the blockchain. Their system leverages smart contracts and architecture based on a permissioned blockchain (Hyperledger Fabric) to facilitate increasing automation of compliance verification and improve both traceability and transparency into the supply chain. In addition to this, it may contain QR code-based product authentication for end-users and Off-chain storage solutions for scaling and data privacy. This study aims to analyze and address the suitability of blockchain technology in fostering the transparency, efficiency and compliance of Halal supply chains and to provide a scalable system architecture for addressing the issues of existing systems. It is with the above rationale that this paper can contribute to the existing body of literature, to build upon the findings obtained in understanding the modus operandi of the powerful blockchain technology to fit the specific needs of Halal supply chain and develop an updated avenue for a robust and seamless ecosystem.

II. LITERATURE REVIEW

As the creator of Bitcoin, Nakamoto [1] introduced the concept of blockchain upon which led to the concept of an immutable ledger. Pilkington [10] highlighted decentralization, transparency, and immutability — the basic principles of blockchain which are vital for digital ecosystems. The Government [14] has introduced research into blockchain capability to increase transparency and assurance in a variety of sectors, including food supply chains, in the UK. Saberi et al. [6]–elaborated on how blockchain can help to promote sustainability in supply chains by creating greater transparency and trust between stakeholders. In a lesser-known application within the textile industry, for instance, blockchain enables organic certification and contamination tracing. Azzi et al. [16] demonstrated how blockchain's potential will help make global supply chains more efficient and resilient. They [7] also proposed distributed ledgers for manufacturing and showed that it can streamline operations while keeping the data secured utilizing blockchain. Hyperledger Fabric originated as a permissioned blockchain platform, and its targeting of supply chains was in part due to the focus on scalability, access control and high throughput [9]. Its smart contracts offer the tempting idea of automating compliance processes. However, Reyna et al. [12] that the real time monitoring of IoT based blockchain is still in infancy due to computation cost, scalability issue and protocol standards violation. Pasupuleti et al. [15] and extended it by combining Blockchain with machine learning, in particular for improving logistics and inventory management.

Zyskind et al. [4] enabled decentralization of data privacy over blockchain allowing data sharing without revealing sensitive data. This is an important capability, especially in supply chains, where sensitive information is exchanged between stakeholders. Though their treatment in the slaughtering process which is Shariah-compliant cannot be disputed, halal supply chains are a cocktail of the various players that are for the most part diverse but also bound by strict Shariah compliance as per requirements laid down by the certification body relevant to each supply chain. These include end-to-end traceability to ensure Halal integrity, comprehensive documentation and alignment with religious principles that mandate immutable records keeping and transparency [8]. Mansoor Sheikh [8] created a need for better integrity and transparency in Halal supply chains while HML [9] proposed a framework for achieving supply chain integrity of food and non-food Halal products and Muthuprasad et al. In [9], a framework of utilizing blockchain to enhance traceability and certification process was presented. Ali et al. [13] proposed blockchain architecture for Halal food supply chains, emphasizing upon using technology to address Shariah compliance together with sustainability outcomes. Reyna et al. [12] and Pasupuleti et al. Respectively [15], integrating different IoT and machine learning methods are proposed to enable real-time monitoring and predictive analytics in Halal supply chains.

However, most of the existing attempts in the literature are focused on the applications of blockchains in supply chains [2], [4], [16], and there are also only limited works addressing their adaptations in Halal-specific contexts. The research is mainly on transparency and efficiency of operation whereas the operation is lacking Shariah complaint mechanisms. To address this issue, this paper introduces a blockchain-based architecture which incorporate Hyperledger Fabric, IoT and machine learning for realizing transparency, scalability and Shariah-compliant requirements. Blockchain cooperation with cutting-edge systems to meet the energetic

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call for international supply chain should be wanted in future analysis.

III. METHODOLOGY

The development and evaluation of the proposed blockchain-based Halal supply chain management system includes the methodology clearly illustrated. This process was conducted to as certain that the target system resolves the critical issues in Halal supply chains including low efficiency, low transparency as well as Shariyah compliance. The steps in the methodology directly addressed the research objectives and assured the practicality of the system.

A. System Analysis

In the first phase we studied the existing Halal supply chain ecosystem to understand its pain points and needs. An extensive review of relevant industry and academic literature was undertaken in order to identify the discussed inefficiencies in Halal supply chains, the typical challenges in upholding Shariah compliance, and the potential remedies that blockchain technology could provide.

B. Framework Design

To overcome such outlined challenges, a blockchain-based framework was proffered. The framework consisted of the following key components:

- *Architecture of the permissioned blockchain:* The system used Hyperledger Fabric as its permissioned blockchain platform due to its scalability, access control, and support for confidential transactions.
- *Technical Elements:* Ensuring secure and efficient transaction validation through endorsement of transactions as well as ordering services capabilities through the use of Practical Byzantine Fault Tolerance (PBFT) consensus mechanism across various forms of node roles.
- *Secure Channels:* Implemented encryption-based communication channels for secure data sharing based on stakeholder needs.
- *Smart Contracts:* Modular smart contracts were established to enable automation of compliance verification at every layer of the supply chain. The rules were cemented by the application of Shariah rules into the contract logic, allowing verification of raw material certifications against pre-approved databases held by the Shariah Boards as well as real-time alerts for certification updates and validation.
- *Cryptographic Algorithms*: Secure Hash Algorithm (SHA-256) was employed at various stages to secure the privacy and integrity of data. Preventing unauthorized modification of data was crucial for securing the system.
- *Integration with Existing Systems*: QR code-based product authentication was used to enable customers to authenticate Halal certifications and trace product lifecycles.

C. Implementation

The following tools and techniques were used to build and test the blockchain framework:

- *Simulation Environment:* To assess performance, the system was tested via Hyperledger Caliper, which provides various performance metrics like transaction speed, throughput, latency, etc. Scalability tests were similarly run, and new nodes were added to the network to confirm a consistent performance.

- *QR Code Generation:* QR codes were created, associated with blockchain entries, to allow end-users to verify products and obtain in-depth supply chain information.

- *Data Storage Design:* All detailed documents are stored off-chain to optimize the performance of the blockchain process, yet they can be verified against the on-chain data by using cryptographic hashing.

D. Evaluation

- *Audit Efficiency:* Regular audits confirmed compliance as well as data integrity.

- *Performance Metrics:* Analyzed transaction throughput and latency and assessed scalability by expanding the number of network nodes.

IV. RESULTS

A. System Architecture:

Key Components are:

- *Stakeholders:*
  - Raw Material Supplier
  - Manufacturer
  - Distributor
  - Retailer
  - Customer
  - Shariah Board (Certification Authority)

- *Blockchain Model:* In this context, we propose a Permissioned Blockchain system. As a first step, a permissioned blockchain restricts information-sharing to authorized parties only such as certified suppliers/manufacturers, etc. This allows you to take advantage of blockchain's immutability while still protecting data confidentiality.

- *Smart Contracts:* Smart contracts automate the process of verification for compliance [17]. For example, a smart contract enables the acceptance of raw materials only if approved by the Shariah Board and it remain same for the other elements of the supply chain.

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- *Database Integration:* The transaction data is stored on the blockchain in hash format meant to be immutable. Audit Reports and Certifications: Off-chain record in a secured database [4].

B. Data Flow

Suppliers of raw material upload information about their products such as Halal certification to the blockchain [6]. The certifications are then reviewed by the Shariah Board, which approves (green node) or rejects (red node) the materials [3]. Approved materials move down the supply chain to manufacturers, distributors and retailers. Customers can scan QR codes to see the whole product lifecycle and confirm Shariah compliance [7].

C. Blockchain Model Selection

Public blockchains are avoided in favor of permissioned blockchains for [5]:

- Participation by Certification: Only those entities having certification can access data.
- Scalability: Permissioned blockchains process transactions quickly because they have a smaller number of nodes than public blockchains.
- Confidentiality: Sensitive data like proprietary manufacturing processes is not available to unauthorized entities.

Table- 1: Features of Permissioned Blockchain [2]

Feature	Hyperledger
Access Control	Restricted to authorized participants
Transaction Speed	Faster
Cost	Lower
Privacy	High

D. System Diagram

The high-level architecture showing the interaction of stakeholders, Shariah Board, blockchain, and the database has been uploaded.

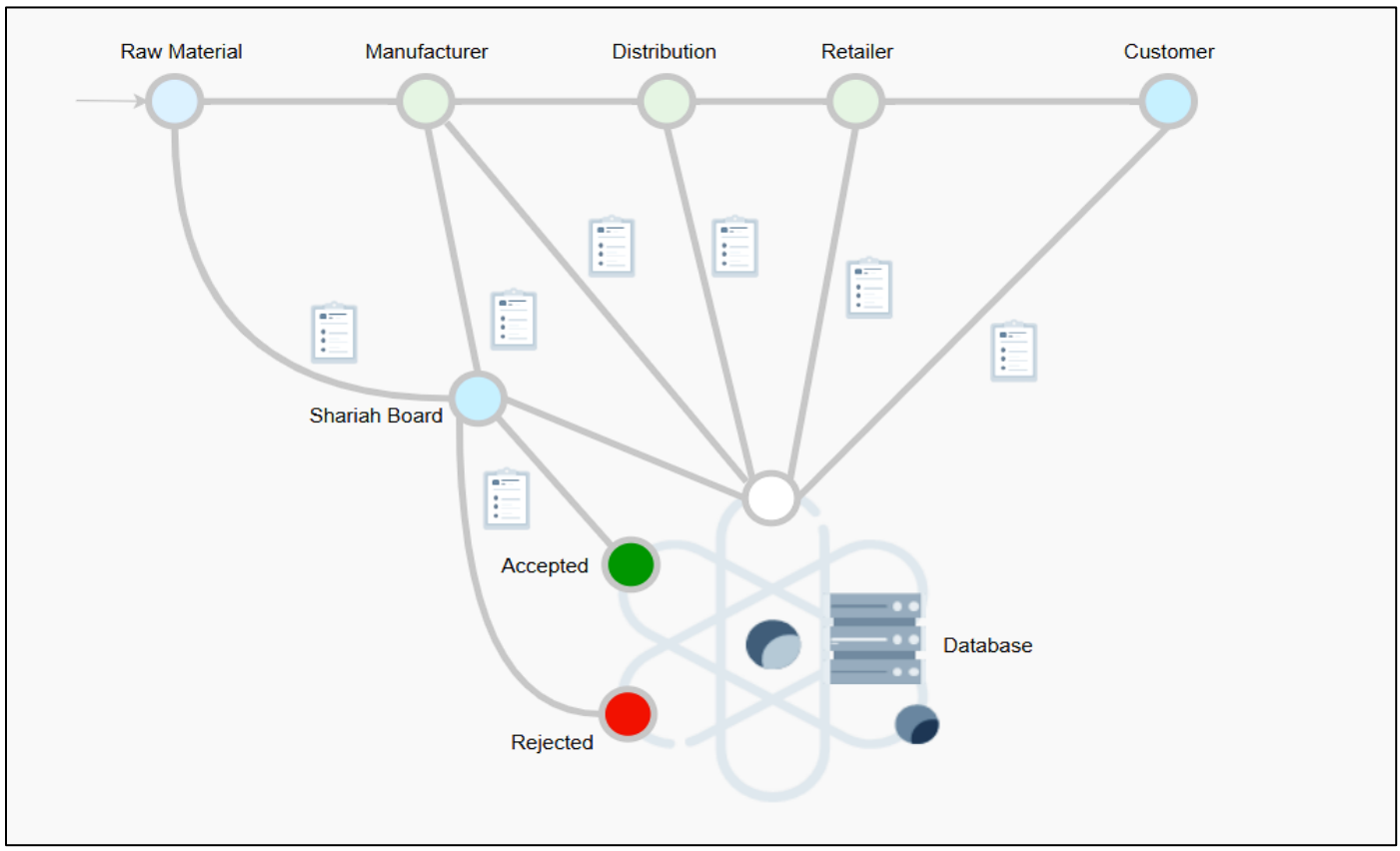

Fig- 1: Simplified Proposed Halal Supply Chain Architecture

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E. Shariah Compliance Mechanism

➢ *The Shariah Board's Role*

The pre-Retirement modules of Life Stage module are composed of Islamic material approved by an authorized Shariah Board. The decisions made by the board are stored on the blockchain, ensuring that they are transparent and traceable [3], [6].

➢ *Implementation of Smart Contract*

The usage of Smart Contract on Blockchain for Material Approval: Raw materials are approved by smart contract based on Shariah certificate [1].

Example Code (Pseudocode):

```
if material. if certification == "Shariah_Compliant":
        approveTransaction()
else:
        rejectTransaction()
```

Process Compliance: Manufacturers upload process details that are reviewed by the Shariah Board and approved.

➢ *Customer Verification*

In this way, end-users can do the same by scanning QR codes placed on product packing to [7]:

- Double check the Halal certification of the product.
- Trace the journey of the supply chain and View Shariah Board approvals.

F. Data Auditing System

➢ *Immutable Records*

Data recorded with blockchain cannot be manipulated. This feature is essential to establish trust in the Halal certification process [5].

➢ *Periodic Audits*

Auditors have access to transaction records and certifications through the system for periodic review. Detects non-compliant actions and triggers alerts using smart contracts [4].

➢ *Off-Chain Data Storage*

To increase performance, large documents (complete audit reports) are kept off-chain and only their hash is stored on the chain for verification purposes.

➢ *Implementation Plan*

- *Technology Stack*
  - ✓ Blockchain Framework: Hyperledger Fabric
  - ✓ Database: MongoDB used for off-chain storage

- *Deployment Steps*

✓ Configure the permissioned blockchain network.
✓ Smart Contracts Development and Deployment
✓ Integrate with Shariah Board certification system.
✓ Pilot test with a few suppliers and manufacturers [8].

V. CONCLUSION

The Halal supply-chain management by utilizing blockchain technology providing Shariah compliance and adding the transparency and efficiency to the entire process would lead to an industrial revolution. In fact, the outcomes of this research have shown an immense variation of compliance verification, traceability, and integrity of data. Such results have highlighted the disruptive impact blockchain can play in solving conventional supply chain problems, creating confidence among its constituents. The proposed system also offers wide basis for future innovations, where predictive modelling and real-time monitoring through integration of machine learning and IoT can be developed. Right now, initial bottlenecks in implementation are severe onboarding complexity issues, and besides, it has not been made standard to certify. So these challenges can therefore be reduced by presenting the issues in civil yet effective manner i.e. a phase rollout as well as government incentives as well as cross-border collaborations. Thus, the outcome of such a study has implications not only for enhanced Halal Trade internationally but also as a gauge threshold technology usage versus ethics in supply chains. Future enhancements to the system depend on additional field pilots in the real world or long-term studies in these real-world settings, which will provide data on its scalability in large domains. This proposed system uses two of the most demanded properties of block chain in correcting sucks traditional supply chains inefficiency and also at the same time augmenting their powerful collaboration, validation capabilities. Furthermore, this future work is needed regarding the implementation of a pilot system and real case study to validate the proposed framework. Additionally, several advantages can be obtained when applying machine learning to IoT by focusing on predictive analysis as well as decision making through real-time data stream monitoring; however, a more in-depth analysis and research should be done towards the integration of machine learning with IoT.

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