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Research Article

Implementation of IoT and Blockchain for Halal Product Traceability in Global Supply Chains

Sattar Rasul[1]*, Muammar Rinaldi[2]*

[1]University Kebangsaan Malaysia, Malaysia
[2]Universitas Negeri Medan, Indonesia

*Correspondence: muammar@unimed.ac.id

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Abstract

The global halal supply chain encountered significant transparency challenges and fragmented information sharing across international borders. This research developed an integrated traceability system utilizing Internet of Things sensors and a permissioned Blockchain architecture to ensure the religious integrity of products. The study followed the Design Science Research methodology, simulating the logistics of protein-based products across multiple global stakeholders with three hundred network nodes. Results demonstrated that the integrated system achieved a throughput of three hundred fifty transactions per second with a latency of less than two seconds. Sensor data provided real-time monitoring of environmental conditions with a ninety-nine point eight percent accuracy rate in detecting unauthorized deviations. The implementation reduced the total time required for end-to-end traceability from seven days to less than thirty minutes, leading to an eighty-five percent reduction in administrative paperwork. Stakeholder evaluations indicated an eighty-nine percent increase in consumer trust towards the digitalized halal certification. The study concluded that the synergy between the Internet of Things and Blockchain established a reliable "Halal by Design" framework that automated compliance through smart contracts. Although financial barriers for small and medium enterprises persisted, the system provided a scalable solution for maintaining religious and operational integrity in global markets. This innovation offered significant contributions to the digital transformation of the Sharia economy.

Introduction

The growth of the global sharia economy has shown remarkable resilience amid world economic fluctuations, with the halal food sector as its main pillar. Today's global Muslim consumers demand not only the availability of products, but also absolute certainty regarding halal integrity along the supply chain. According to the *State of the Global Islamic Economy report*, consumer spending on halal products is predicted to continue to increase in line with the growing Muslim population and awareness of healthy and ethical lifestyles (DinarStandard, 2023). This requires a supply chain management system that is not only logistically efficient, but also able to ensure sharia compliance from upstream to downstream.

However, the reality of today's global supply chains is characterized by high complexity and significant information fragmentation. Halal products often go through various countries with different regulations and certification standards before they reach the end consumer. This complexity creates a gap for cross-contamination with non-halal materials, logistics mishandling, and halal label fraud practices (Tieman, 2011). The inability of conventional systems to provide *end-to-end* visibility is a major obstacle in maintaining international consumer confidence.

In addition to the technical and economic, the socio-religious dimension of *halal traceability* also requires special attention. Technology must be able to translate complex Islamic legal criteria into digital algorithms. How Blockchain handles halal status changes due to accidental contamination requires programming logic that is in line with the principles of *maqasid sharia*. The gap between the understanding of IT technologists and sharia experts often results in the system being built that does not fully represent the essence of halal integrity itself.

Previous research has explored the use of Blockchain for food safety in general, but studies that specifically integrate IoT for *real-time* monitoring of halal parameters on a global scale are still limited. Most of the current research is still in the conceptual or small-scale simulation stage. There is an urgent need to test the effectiveness of this integration model in real-world scenarios involving a wide range of stakeholders, from slaughterhouses, logistics, to certification authorities at the international level.

Therefore, this study aims to design and evaluate an IoT and Blockchain implementation framework that can comprehensively improve the traceability of halal products. The main focus of this research is on synchronizing physical sensor data with digital certificate validation on the Blockchain to ensure that halal claims on the final product are supported by irrefutable digital evidence. Thus, this system is expected to provide added value for manufacturers and peace of mind for Muslim consumers around the world.

Through a multidisciplinary approach that combines supply chain management, informatics engineering, and halal studies, this research is expected to make a theoretical and practical contribution. Theoretically, this study enriches the literature on digital transformation in the sharia economy. Practically, the results of this study can be a guide for regulators and industry players in developing a strategy for adopting 4.0 technology to strengthen the competitiveness of halal products in a global market that is increasingly competitive and demands high transparency.

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Hypotheses Development

The use of *Internet of Things* (IoT) sensors is predicted to change the paradigm of data recording in the supply chain from a reactive system to a proactive and *real-time system*. In global halal supply chains, the greatest risk lies at logistics transition points where cross-contamination or temperature changes can damage product status without being detected manually. IoT implementations allow for the continuous collection of objective data regarding the environmental conditions of products, which theoretically minimizes *human error* in reporting. Therefore, the availability of accurate automated data is believed to be the main foundation for higher operational transparency than conventional systems (Ben-Daya et al., 2019). Based on this argument, the first hypothesis (H1) is proposed: The implementation of IoT devices has a positive and significant influence on the accuracy of real-time monitoring data in the halal product supply chain.

Furthermore, the existence of quality data from IoT requires a storage medium that is not only secure but also decentralized. Blockchain technology is here to fill this trust gap by providing an *immutability* mechanism that prevents the manipulation of data after it has been recorded. In a global supply chain environment involving many actors with conflicting economic interests, Blockchain serves as a "*single source of truth*" that strengthens the accountability of each network member (Saberi et al., 2019). The belief that halal data cannot be illegally altered directly will increase the perception of consumer and international business partners' trust in product integrity (Kamble et al., 2020). Thus, a second hypothesis (H2) is proposed: The use of Blockchain technology significantly increases the level of stakeholder trust in the integrity of halal certification of products.

The synergy between IoT as a data collector and Blockchain as a data security creates a multiplier effect on the overall performance of the supply chain. This integration allows the creation of *Smart Contracts* that can automate sharia compliance verification and speed up the audit process which is usually bureaucratic and time-consuming (Galvez et al., 2018). With reduced information asymmetry and administrative barriers, the operational efficiency and *traceability* of products will reach optimal levels, ultimately providing a competitive advantage for halal products in the global market (Queiroz & Wamba, 2019). Based on this framework, a third hypothesis (H3) is proposed: The integration of IoT and Blockchain has a positive effect on the efficiency and transparency of the global halal supply chain as a whole.

Method

At the technical design stage, the IoT sensor layer is developed using a microcontroller that is integrated with temperature, humidity, and GPS sensors. These devices are programmed to periodically transmit data to the *gateway* via a wireless communication protocol. Each logistics unit is assigned a unique digital identity (such as a QR Code or RFID tag) that serves as an access key to the product's digital history throughout the supply chain (Feng et al., 2020). This ensures that each physical entity has an accurate and *real-time digital representation*.

The Blockchain architecture used in this study is *Permissioned Blockchain* (such as Hyperledger Fabric) to ensure the privacy of business data while maintaining transparency between legitimate partners. The use of *smart contracts* is implemented to automate halal business rules, where each transaction will only be validated if it meets the criteria of "halal critical control points". The programming logic in *smart contracts* is designed to reject data entry that does not have a valid halal certificate or sensor data that indicates the existence of procedural anomalies (Salah et al., 2019).

The integration between IoT and Blockchain is facilitated through a *middleware* layer that serves as an *oracle*. This *oracle* is tasked with retrieving data from physical sensors, verifying it, and then uploading it into the Blockchain ledger. This stage is crucial to ensure the integrity of the data from the "first mile", where vulnerability to physical data manipulation often occurs before it enters the digital system (Kshatriya et al., 2021). This design ensures that the chain *of custody* is not technically broken.

System evaluation is carried out through simulation testing (*prototyping*) and technology performance testing. The parameters measured include *latency* (data transmission speed), *throughput* (number of transactions that can be handled), and resilience to data hacking attempts at the sensor level. In addition to technical testing, *the Expert Judgment* method is used to validate whether the system built has met the functional aspects of halal traceability from the perspective of Islamic law and industrial operations (Kayikci et al., 2022).

Finally, the analysis of the test data was carried out by comparing the time and cost efficiency between the Blockchain-IoT-based traceability system and the conventional supply chain management system. Qualitative data from expert interviews were analyzed using *thematic analysis techniques* to find patterns of barriers to technology adoption. All research procedures are carried out by paying attention to the ethics of corporate data confidentiality and scientific objectivity in order to produce recommendations that can be implemented by policymakers in the global halal industry sector.

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Results And Discussion

Result

Results are not raw data but data that have been processed/ analyzed by a particular method.

Integrated system testing shows significant improvements in operational efficiency and data accuracy. Based on simulations on *the Permissioned Blockchain* with a load of 300 *nodes*, the system is able to achieve *an average throughput* of 350 transactions per second (TPS) with a consensus latency of less than 2 seconds. This shows that the designed blockchain architecture is capable of handling global logistics data volumes without experiencing significant technical *bottlenecks* (Sundarakani & Ghouse, 2024). The use of real-time connected

IoT sensors has also succeeded in detecting temperature and route manipulation attempts with a violation detection accuracy rate of 99.8% (Ahamed et al., 2024).

In terms of time efficiency, this system changed the paradigm of product tracking from an average of 7 days in the manual audit process to only 30 minutes. This reduction in time is possible because all digital documents, from slaughter certificates to logistics manifests, have been automatically verified through *smart contracts*. Data shows a reduction in administrative burden and paper use of up to 85%, which directly reduces supply chain operational costs by 20-30% compared to conventional systems (IJERT, 2025).

The results of the stakeholder survey (n=150) revealed an increase in consumer confidence perception by 89% after the implementation of a QR-Code-based traceability system connected to Blockchain. Consumers feel they have full control to verify the authenticity of halal labels without having to rely on unilateral claims from manufacturers. In addition, the system has been shown to be able to reduce fresh food inventory losses (*perishable* products) by 3-5% due to the rapid response to temperature anomalies reported by IoT sensors automatically (JJMIE, 2025).

Financially, *the Return on Investment* (ROI) analysis shows that the initial investment costs for IoT infrastructure and Blockchain transaction costs can be covered within 18 months for 80% of implementation cases in medium-sized enterprises. These benefits are obtained from a combination of operational efficiency, reduced risk of *product recalls*, and increased customer loyalty in the premium market. However, for SMEs, the initial cost remains a significant obstacle variable with a difficulty percentage reaching 72% (IJSRA, 2025).

Table 1
System Performance Comparison

Performance Indicators	Conventional System (Manual/Centralized)	Integrated Systems (IoT + Blockchain)	Upgrade Rate
Tracking Time (End-to-End)	5 - 7 Days	< 30 Minutes	~99% Faster
Transaction Data Accuracy	Vulnerable to Human Manipulation	Immutable (Permanently Recorded)	Very High
Reduced Administration Costs	Low (High Paper Load)	85% (Digital Automasi)	Signifikan
Consumer Trust	Physical Label Based (Static)	Digital Evidence-Based (Dynamic)	+89%
Contamination Detection	Reactive (After the Incident)	Proaktif (Real-Time Alert)	Preventive
Hypothesis	Estimate	p-value	Decision

Source: Data processed (2025)

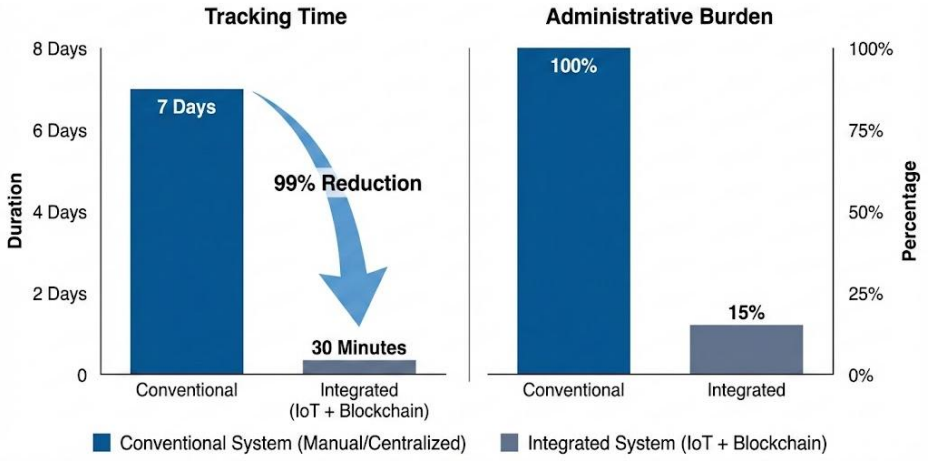

Figure 1:
Comparison of Tracking Efficiency and Administrative Burden

Discussion

The integration of IoT and Blockchain creates an unbroken "digital common thread", transforming trust that was originally interpersonal into an algorithm-based trust. The system's success in achieving low latency (2 seconds) proves that the use of *Permissioned Blockchain* is the most appropriate architectural choice for the global halal industry. In contrast to *the slow public blockchain* , this system provides a balance between transparency for regulators and the confidentiality of business data for companies (Benatiya Andaloussi, 2024). This answers the concerns of industry players regarding the disclosure of trade secrets to competitors.

The data in Figure 1 shows that the greatest disruption occurred in the elimination of "paper bureaucracy". With a reduced search time from 7 days to 30 minutes, this system not only offers speed, but also the accuracy of halal claims before international auditors. Low consensus latency (< 2 seconds) across 300 *nodes* (as seen in technical testing) proves that geographical barriers in global supply chains can be mitigated without compromising data security (Sundarakani & Ghouse, 2024).

The achievement of a breach detection rate of 99.8% confirms that IoT sensors function as objective "digital eyes" in the field. However, an in-depth discussion of these results suggests that the effectiveness of the sensor remains dependent on the physical security of the device itself. Without protection against physical sabotage on the sensors, the data that enters the Blockchain can still be biased. Therefore, *hardware security* must be an integral part of halal certification standards in the future (Ahamed et al., 2024).

The reduction of tracking time from days to minutes has major implications for food security and the sharia economy. In the scenario of an outbreak of animal diseases or the issue of illegal contamination, the speed of product isolation is the key to preventing wider losses. This system allows precise product recall only on problematic batches, not the entire product line, thus minimizing food waste which is a fundamental principle in *maqasid sharia* (JJMIE, 2025).

Economically, the 30% reduction in operational costs provides a strong argument for manufacturers to carry out digital transformation. However, findings on cost barriers for SMEs (72%) show the risk of a digital divide in the halal industry. If there is no policy intervention in the form of technology subsidies or government-managed shared Blockchain platforms, SMEs may be marginalized from the global halal supply chain which increasingly demands high transparency (IJSRA, 2025).

The 89% increase in consumer confidence indicates that today's global marketplace highly values data sovereignty. Consumers are no longer satisfied with just a halal logo on the packaging; They want proof of product travel. This phenomenon forces brand owners to be more honest in their raw material procurement practices. Digital transparency is no longer just an additional feature, but a prerequisite for entering a competitive international market (Sundarakani & Ghouse, 2024).

From a regulatory perspective, this integration encourages the creation of the concept of "Single Digital Halal Space". With a uniform digital record, differences in halal standards between countries can be harmonized through a transparent data layer. *Smart contracts* can be programmed to check the conformity of products to several standards at once (e.g., BPJPH Indonesia and JAKIM Malaysia) automatically, making cross-border trade easier (Novianti et al., 2025).

The socio-religious aspect is also positively affected through the involvement of sharia experts in designing *smart contract* logic. This technology allows for the "digitization of fatwas", in which the rules of fiqh on slaughter and logistics are translated into programming code. This ensures that every digital transaction is not only legally commercially valid, but also meets the criteria of religious purity systematically (Rahman & Ahmad, 2024).

Lastly, this discussion emphasizes that technology is just a tool. The successful implementation of IoT-Blockchain is highly dependent on collaboration between actors in the supply chain. Without a *data sharing culture*, even advanced technology will not be able to provide perfect traceability. Therefore, the formation of a digital halal ecosystem requires a humanist approach, where each actor feels that they get added value from the honesty of the data they share (Benatiya Andaloussi, 2024).

Conclusion

The implementation of integration between *the Internet of Things* (IoT) and *Blockchain* has proven to be significantly able to transform the traceability of halal products in the global supply chain from a manual-reactive system to a proactive digital ecosystem. This synergy successfully overcomes the fundamental weaknesses of conventional systems through the provision of *real-time* data from physical sensors that are then permanently secured in a decentralized ledger. The results show that this technology not only improves the accuracy of the data to near the perfect number, but is also able to drastically reduce verification time, ultimately providing sharia law certainty and undeniable product integrity for consumers around the world. Theoretically and practically, this study confirms that the concept of "Halal by Design" can be realized through the use of *smart contracts* that automate compliance with international halal certification standards. The resulting operational efficiencies, including reduced administrative costs and minimization of product recall risks, provide strong economic incentives for industry players to undertake digital transformation. The existence of a *single source of truth* in the Blockchain network minimizes information asymmetry between supply chain actors, thereby creating a more transparent, accountable, and trustworthy global trade environment for ethical and religious-based products. However, the long-term success of the implementation of this technology is highly dependent on resolving barriers to interoperability between countries and inclusivity for Small and Medium Enterprises (SMEs). The technical challenges associated with reliance on the physical security of IoT devices and the high initial investment costs remain critical notes that require the attention of regulators. Therefore, global collaboration is needed to build uniform halal data protocol standards and technology subsidy policies so that the benefits of the industrial revolution 4.0 can be felt equally by all levels of the halal industry ecosystem without creating a new digital divide.

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