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Blockchain-Based Traceability System to Support the Indonesian Halal Supply Chain Ecosystem

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Abstract: The halal industry is constantly developing into a broader concept of the Islamic economy, an economic activity that follows the Islamic-based principle. As a populous Muslim country, Indonesia follows the growth trend by aiming to dominate the global halal market. The strategy is to improve the current halal assurance process. Presently, the technology and procedure do not provide enough process transparency, traceability, and granularity of information. To achieve the strategic goal, a technological change is needed. A new emerging technology, blockchain, may potentially answer the challenge. This study's first objective is to discuss improving the current assurance practice in the Indonesian halal supply chain ecosystem, particularly in the meat industry. The second objective is to construct a traceability system model for the supply chain. Our goal is to propose a blockchain-based halal traceability system model. The model can be enhanced to be a national standard tool to develop the economy towards a sustainable supply chain.

Keywords: blockchain; halal supply chain; traceability system; slaughterhouse

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1. Introduction

Indonesia is the largest Muslim country globally, with a majority of the citizens being Muslim. There are around 1.8 billion Muslims worldwide and 300 million in Indonesia. The market opportunity is USD 1.9 trillion, and the domestic opportunity aggregate is USD 184 million. The government bodies under the ministry of religious affairs are tasked to regulate and maintain the implementation of sharia law in Indonesia to fulfill the halal requirement, especially in the food supply chain. Halal food is any food consumed by Muslims and must follow the guidelines and observances of Islamic law.

There are three bodies involved in halal food assurance. The first, *Majelis Ulama Indonesia* (MUI), is the Indonesian Islamic scholarly body providing legal measurements. The second, *Badan Penyelenggara Jaminan Produk Halal* (BPJPH), provides halal certification. The third, *Lembaga Pengkajian Pangan, Obat-obatan, dan Kosmetika Majelis Ulama Indonesia* (LPPOM MUI), tests, verifies, and validates food halalness. At the decision, MUI serves a sitting to justify whether a business entity may or may not receive a halal certificate. The halal certificate published by BPJPH acts as proof that any business has justified its production operation in compliance with sharia law or halal principles. The certificate expresses that halal bodies guarantee the company produces halal products, which gives a guarantee to the market.

The current Indonesian vice president, Ma'ruf Amin, states that Indonesia should aim to dominate the global halal market (Office of Assistant to Deputy Cabinet Secretary for State Documents & Translation 2021). In this regard, Indonesia should participate in constructing and supporting the development of the halal value chain across nations while being a center of the sharia economy across the globe. The ambition lies in the Indonesia Sharia Economy Masterplan (SEM) (Ministry of National Development Planning of the Republic of Indonesia 2019). One of the strategic plans to achieve the goal is to enhance

Indonesia's digital economy and halal value chain. Some of the programs to support it are the halal hubs in each district/province, halal certification, and an integrated halal traceability system. For the time being, an established program is a halal certification. A halal certification even reached the SMEs in Indonesia, providing halal assurance towards products in their market. In current practice, the three halal bodies provide a halal warranty by making businesses put halal logos on their products. Additionally, consumers can check the halal product status on the MUI official website.

However, there are some drawbacks to the current mechanism (Novianti et al. 2020): First, the detailed information about halal products is only available by one of the halal bodies, LPPOM MUI. The second is the centralized food processing tracking system, resulting in less transparent information on food and only being accessible by those who own the data and control it. The problem complexity grows if we include the possibility of late information updates on the current MUI official website. Thus, developing a verifiable, safe, transparent, shared, or distributed database is essential to store halal supply chain information activities (Zainal Abidin and Putera Perdana 2020). Combined with Indonesia's vision to dominate the global halal market and the current mechanism issue, this becomes the urgency for our study.

Foodborne disease prevention is an essential factor that urges the implementation of a traceability system. The mad cow outbreak happened in Britain almost thirty years ago, from 1986 through 2001 (CNN Editorial Research 2021). If humans consume contaminated beef, it may cause fatal brain disease. Since the outbreak, a tracing mechanism using a barcode ear tag has been implemented to prevent contaminated meat from being consumed. The same solution applies to another supply chain that concerns halalness. The goal is to avoid the consumption of haram products, yet the barcode technology alone is not sufficient to give real-time assurance.

Therefore, the need comes for a new tracing and assurance mechanism that first makes halal assurance accessible by each stakeholder in the supply chain, thus providing transparency and direct halal commitment for consumers. Second, it must be safe; therefore, no counterfeit halal certificates are distributed to businesses because halal traceability relates to increased confidence among consumers in the food safety of halal foods (Vikaliana et al. 2016). The current technology capable of keeping up with particular needs is blockchain. Together with Artificial Intelligence, blockchain is a part of the leading technology in the digital economy, specifically following massive personalization trends. This study proposes a model for tracing systems based on blockchain technology to solve the previously mentioned issues in the food industry.

The first use case of blockchain technology is in the financial domain, such as cryptocurrency to handle peer-to-peer transactions. Blockchain can make an immutable record, robust to data alteration or tamper-proof, thus providing consistency across the network. Blockchain is also decentralized, combined with the character of immutable records, which results in transparency between members of a network. The idea of implementing blockchain in various industries has exponentially gained popularity recently. For example, blockchain is used to provide a secure and reliable property registry system (Shuaib et al. 2020); blockchain is implemented to prevent counterfeiting in the wine industry (Danese et al. 2021); blockchain acts as a tracking mechanism in smart cargo transportation (Baygin et al. 2022); and blockchain provides data integrity in agriculture (Xu et al. 2020). The mentioned ideas prove the expansion of blockchain technology applied beyond the financial industry.

The contribution of this study is an improvement of the halal traceability model for the current state of the meat supply chain in Indonesia. First, we build data attributes based on Indonesia's meat supply chain. Second, we design the *off-chain* and *on-chain* processes of the system with intention of showing the whole mechanism on each different level. Our proposed model complements the previous work of (Rejeb 2018; Novianti et al. 2020; Surjandari et al. 2021). From Rejeb, we top off the model by reducing the number of participants on the blockchain network, thus constructing an original block structure. From Novianti's model, we bring it to perfection by designing the model to be on a private blockchain ecosystem since it offers better participant management. Additionally, from Surjandari's model, we involve halal bodies in the blockchain network to complete the model. A further contribution is analyzing and comparing blockchain infrastructure candidates for future research goals, testing model feasibility, the transaction cost (blockchain operational cost), and discussing constructing the model on an open-source platform or developing an original blockchain environment from scratch.

The paper is arranged as follows: The next section is the literature review of previous studies regarding blockchain technology and the halal supply chain. Section 3 presents the research methodology. They are followed by Section 4 to introduce the proposed model construction, a blockchain-based halal traceability system. Section 5 presents the results and discusses how the model should work. Section 6 summarizes the study and provides a suggestion for further research.

2. Literature Review

2.1. Blockchain Principle

Blockchain is said to be founded by Satoshi Nakamoto in 2009; his white paper formulated the practice of electronic cash in a peer-to-peer network. Blockchain is a technology where several data blocks are combined into one serial form and protected with cryptography. The serial form is what we call a 'chain', and cryptography that also works as the connector of each block is called the hash. Each hash creation is unique because its form is ever-changing whenever we put something on the block. This mechanism creates powerful protection to prevent data from being tampered with. Blockchain is also known as a distributed ledger, meaning everyone on the network can see and verify each transaction event. The mechanism to verify transactions is through a consensus, i.e., proof-of-stake or proof-of-work. From this, blockchain is capable of creating untampered data records, thus creating transparency of data flow on the network.

Blockchain has attracted researchers to study its opportunities in different domains as new emerging technology. For the past several years, studies have attempted to discuss it. Some studies agree that blockchain can be implemented in multiple industries. Those industries are pharmaceutical (Musamih et al. 2021; Panda and Satapathy 2021), water (Mahmoud et al. 2021), food supply chain (Vivaldini 2021; Danese et al. 2021; Iftekhar and Cui 2021), property (Shuaib et al. 2020), agriculture (Xu et al. 2020; Caro et al. 2018), retail (Yacoub and Castillo 2021), logistic (Baygin et al. 2022), and automotive (Kamble et al. 2021). Above all in these industries, blockchain implementation is a large part of their supply chain operations. Whether it is a supply chain component or other implementation, blockchain solves the dark side of interorganizational relationships: information asymmetry among stakeholders (Mishra et al. 2021).

Mahmoud et al. (2021) developed WDSchain, an open-source MATLAB toolbox, to simulate the distribution of water using blockchain technology on water management systems using various consensus mechanisms. The idea behind the development is security issues in water management system metadata. Mahmoud et al. fear there are possibilities of eavesdropping on the water management system if the metadata is transmitted or communicated through cloud technology. Therefore, there comes a necessity to provide a secure communication channel. The WDSchain can support simulation scenarios for stakeholders to develop the desired consensus mechanism. It became an excellent medium for experiments before developing blockchain-based water systems on a preferred blockchain platform. Though such technical implementation is on a small scale, and many are still in the conceptual phase, we consider this study a massive step for a blockchain developer to create an ideal system that integrates blockchain and water systems.

Another possible use case of blockchain is on asset management by the government; Shuaib et al. identify a potential to make blockchain-based land registry systems (Shuaib et al. 2020). A vital issue is storing a document as proof of ownership and entitlement. The blockchain's role is to secure data and enable consensus mechanisms to verify land ownership. Therefore, a blockchain's public record of land ownership is an untampered record to prevent fraud and provide up-to-date information on land records. Merits for the government are on tax collection, increasing record security, and process efficiency.

Blockchain applications in various industries require additional technology, such as the Internet of Things (IoT), which supports blockchain, whose primary duty is to provide secure transaction with an untampered record and distribute that information to the appropriate party. Both techniques are combined mainly by the food industry and logistic industry. Both drive the usage of integrated technology as an asset traceability system such as the pharmaceutical industry. It provides a clear sight to trace the product flow from upstream to downstream and vice versa. Consumer trust may increase because the company can ensure product status and originality.

A study on the wine supply chain proves the desired level of protection to prevent counterfeiting differs in certain variables: customer segment, price positioning, and brand recognition (Danese et al. 2021). Exclusive wine manufacturers tend to use NFC tags associated with mobile applications. This mechanism acts as an unaltered record and traceability using the hash when combined with blockchain. It would provide accessible data for customers, and its strength is more than enough to guarantee nonreplicability. Yet, when it comes to everyday wine, manufacturers prefer entry-level protection, utilizing blockchain to store records to let consumers know that the product has an acceptable quality standard. Our idea for this study is that blockchain applications can be customized to meet the desired guarantee level for targeted consumers. Hence, businesses will not have to worry about utilizing blockchain in various ways as long as it can meet that variable.

The pharmaceutical supply chain is also seen as having an opportunity to provide a blockchain-based anticounterfeiting mechanism. Musamih proposed blockchain-based drug traceability for the pharmaceutical supply chain with Ethereum as the blockchain platform, since traditional solutions lack transparency across participants in this supply chain (Musamih et al. 2021). The model utilizes an IPFS as decentralized storage and smart contracts to efficiently handle transactions. Panda and Satapathy proposed a similar model, simply different in model testing results (Panda and Satapathy 2021). The model by Musamih is tested on the Ethereum platform and is slightly more cost-efficient than the model by Panda and Satapathy, who tested on a private blockchain environment, as the transaction fee is lower on the Ethereum platform. Nowadays, a cargo or shipping company is crucial, considering e-commerce platforms partner up with them to distribute goods. Baygin proposed a solution to enhance the shipping management system; it involves Ultra-High Radio Frequency (UHF-RFID) and blockchain technology (Baygin et al. 2022). The RFID utilization is for tracking devices and blockchain to provide enhanced security. The model addresses traceability and payment issue; thus, the author serves cost analysis to the model implementation. Based on the study, there is a massive benefit in terms of workforce and financials (Baygin et al. 2022). Hence, this is proof that blockchain solutions to enhance the traceability system are beneficial.

There are blockchain solutions for a traceability system suitable for the agri-food supply chain to create transparency and trust among participants. Caro et al. (2018) proposed AgriBlockIoT, a decentralized traceability system for the agri-food supply chain. The model used *from-farm-to-fork* as a use case and tested the performance on two blockchain platforms: Ethereum and Hyperledger Sawtooth. The preliminary test shows that Hyperledger Sawtooth performs better in latency, CPU load, and data usage. Yet, both platforms have different properties and need to be considered further. Another study by Xu et al. (2020) highlights several challenges in the agri-food supply chain. Still, the most important that are covered in our research are falsified information records and various tracing parameters. The challenges are not solely on the agri-food supply chain but could happen in the general blockchain solutions implementation.

Iftekhar and Cui (2021) proposed blockchain for a traceability solution to minimize the contamination of COVID-19 and other pathogens in the frozen meat supply chain.

Earlier, a radical combination of blockchain and DNA coding mechanisms was proposed by Sander et al. (2018). They deemed that the combination may provide nearly perfect assurance for the provenance information on meat products. Yet, in our opinion, the proposed mechanism is too advanced for the current state of the Indonesian meat supply chain. Nonetheless, it is not impossible to implement the idea when the time is right.

Hilten et al. (2020), in a previous study, evaluated the application of blockchain technology in the organic food industry considering European regulations. They believe a simplified certification process impacts fewer costs for all chain partners. On the contrary, we tried to design a blockchain solution for the meat supply chain in light of the halal context. We also aim for our model to be capable of fastening and simplifying the meat certification process.

Until this part of the article, a blockchain-based traceability system seems to be a promising technology to enhance transparency and security in the supply chain of various industries. Before the blockchain era, the traceability of products used technologies such as autonomous fuzzy cognitive maps, barcodes, and RFID (Aung and Chang 2014; Chen 2015). Vivaldini (2021) argues that a blockchain is a complementary tool that does not guarantee food safety. Despite the argument coming from a specific case study (foodservice distribution), we agree on blockchain as a complementary tool due to several factors such as standards of operation discrepancy, regulatory uncertainty issues, and participants' readiness in the supply chain. These factors need to be addressed before the technology implementation is to begin.

2.2. Smart Contract, DAO, Dapp, and IPFS

A smart contract is a series of executable codes designed to operate in a particular blockchain network. The main objective of this contract is to automate and secure transactions. The contract is 'smart' because it only proceeds transactions if the conditions are met. The contract can automate the quality control process in the supply chain domain and prevent error records (Vivaldini 2021).

A Decentralized Autonomous Organization (DAO) is a community-led organization that does not have a central authority. Therefore, there is no structural hierarchy in the organization. The smart contracts are laid as the foundational rules of DAOs. They set rules on certain activities for the members; they can autonomously execute activities such as voting, proposing, etc. When the 'rules' are no longer fit, the members may audit them publicly.

An application built on a blockchain network is called a Decentralized Application (Dapp); it runs on a peer-to-peer (decentralized) network. Dapps are an implementation of the DAO concept, a combination of several smart contracts with user interfaces to perform as a front-end layer that interacts with users. The difference with the typical applications is that a Dapp is likely more robust because the underlying operation happens on a distributed ledger.

An InterPlanetary File System (IPFS) is a distributed file system used to store files. A blockchain network is capable of storing data but unsuited for storing a large amount of data (Sabrina et al. 2019). Because of its decentralized nature, it may build heavy traffic on the network. An IPFS is designed to cooperate with a blockchain network. Each file stored on the IPFS has a permanent address (IPFS address). An IPFS address is then stored on the blockchain network as hashed information inside the transaction block. An IPFS serves as a publicly accessible database, and the blockchain is used to verify the addresses of the files (Triebstok 2018).

2.3. Halal Industry

Halal is a status Muslims give for any action permitted by sharia law, while the opposite of this term is haram. For decades, Muslims worldwide believed they could only consume what goes with the word halal. There is a market for halal products or services among Muslims. The halal industry comprises seven core sectors: food and beverage, finance, clothing, tourism, media, pharmaceuticals, and cosmetics (Indonesia Halal Markets Report 2021).

In 2019, Indonesia's government established a transition period for the business entity to obtain the halal certificate for their products based on their respective categories. For the food and beverages categories, the transition period ends in October 2024; this strategy aims to realize halal assurance according to Act Number 33 of 2014 concerning Halal Product Assurance (LPPOM MUI 2021b). To reinforce the strategy, a new halal certification law was issued; the new law is Government Regulation 39 of 2021. Under the new law, the halal certification assessment covers the materials and production process (storage, packaging, display, and sales) of a product (Medina 2021)—such regulation made it possible for the halal industry to develop innovation.

As a country with a Muslim majority, Indonesia has a halal industry. There are manufactured products with halal logos, meaning the products are halal and guaranteed by halal bodies in Indonesia. In 2020, Indonesia became the leading country as the largest halal consumer market in the world, with a total amount of consumer spending worth USD 184 (billion), whereas USD 135 (billion) comes from the food and beverage sector (Indonesia Halal Markets Report 2021). While the other sectors' worth (in billions of dollars) is as follows: media (USD 20.3), fashion (USD 15.6), pharmaceutical (USD 5.13), cosmetics (USD 4.19), and tourism (USD 3.37) (Indonesia Halal Markets Report 2021).

2.4. Halal Supply Chain

To support the existence of the halal industry, a supply chain that abides by the halal term was laid, known as the halal supply chain. The introduction of halal evolution in supply chain management led to compliance with the halal term (Tieman 2011). In this supply chain lies a guarantee on halal integrity, so Muslims can rest assured with the consumption of their product. This supply chain is about the halal and haram of a product. Supply chain activities on the halal supply chain are no different from other chains, such as sourcing, transporting, and warehousing.

In Indonesia itself, MUI acts as a body to issue a fatwa (religious order) based on sharia law on a particular matter. To proceed with the task, BPJPH acts as a halal certification body that issues halal certification to businesses and then publishes halal certificates after MUI has made the fatwa. While MUI declares a sitting to make a fatwa, another body, LPPOM MUI, analyzes components of a business's products to determine halal and haram in the certification process.

As the main halal body in Indonesia, MUI inspects the halal compliance of slaughterhouses with three mechanisms: an audit each semester, an impromptu inspection, and the expiration date of the halal certificate in certain facilities such as slaughterhouses. From the three joint mechanisms that exist, a public webpage contains information about products that have been verified by MUI and identified as halal products. The verification process was conducted by assessing a particular operation on the business based on specific regulations in Indonesia, which are HAS 23000 (LPPOM MUI 2021a).

Figure 1 shows the current method of how the halal meat supply chain concurs around us in Indonesia.

1. First, the cattle's owner would deliver the cattle to a certain slaughterhouse to go through the slaughtering process. MUI could guarantee the slaughterhouse performs a halal slaughter method if it has a halal certificate. If there are none, MUI can legally consider that the slaughterhouse did not perform the halal slaughter method.
2. After slaughtering, the meats go through identification and packaging
3. Then, its identity is recorded on the slaughterhouse's local database (local DB).
4. The slaughterhouse makes audit documents using the recorded data and then sends them to MUI to verify. The process currently completes every semester. We could presume that MUI guarantees the halalness of the meat distributed once every six months. In such a period, any mistake affecting the halalness of the meats could happen.
5. MUI verifies the audit document.

   a. MUI checks for the halal certificate on a specified slaughterhouse and audit reports determining the status of halal for the meat.
   b. MUI uploads the result on the official webpage. If the specified product exists on the page, MUI guarantees that the product is considered halal.

6. Consumers intent to buy the meat.
   a. Consumers may check the halal status of the products on the MUI official webpage. Consumers can complete the action by inputting the product's name and searching for it.
   b. Last, consumers buy the product where MUI guarantees halalness. The transaction may happen daily in retail stores, supermarkets, or traditional markets.

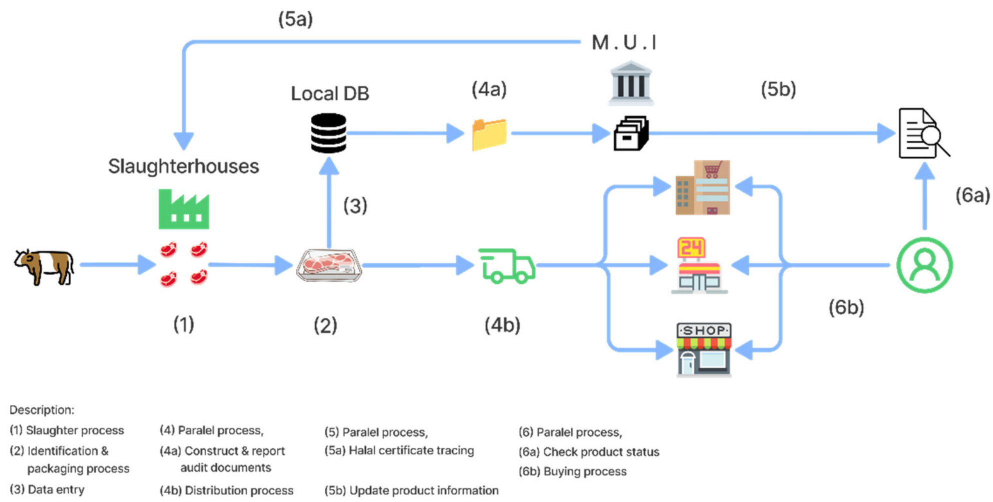

Figure 1. Indonesian halal meat supply chain activities.

From the described mechanisms, a product's halal status is valid as long as the halal certificate of the slaughterhouse is valid. There is a disadvantage to the current means of halal certification shown in Figure 1; the intervals between the audit report documents might take too long and pose risks such as cheating (Ali and Suleiman 2018). We can create a real-time halal assurance that effectively monitors the halal supply chain by using blockchain technology.

2.5. Halal Supply Chain with Blockchain

Tieman and Darun's study is one of the pioneering research projects conducted to find blockchain applications in the halal industry (Tieman and Darun 2017). A blockchain combined with IoT benefits manufacturers, brand owners, and retailers from the halal and reputation management standardization standpoint. This study also points out there is a need for standards of halal that are feasible to be achieved for business owners. Another perspective that the halal supply chain can operate with blockchain technology came from a study by Hew et al., they argue that a blockchain-based halal traceability system is not only hype (Hew et al. 2020). This makes more reason to put the idea of the current study into practice.

In the halal supply chain, a traceability system has certain success factors, and according to Khan et al., there are twelve critical success factors (CSFs) (Khan et al. 2018). Of the twelve variables, two groups of variables are classified with high driving power to change and high dependency: 'Determinant variables' and 'Relay variables'. The determinant variables are 'Government Support', 'Top Management Support', and 'Halal Awareness'. The relay variables that drive and can mediate the influence of determinant variables are 'Training of Employees', 'Dedicated IT Infrastructure', 'Standardization and codification', and 'Coordination and Collaboration among Supply Chain Partners'. Blockchain technology may be placed as the 'Dedicated IT Infrastructure', but other variables such as 'Government Support' and 'Top Management Support' also play roles in granting a successful halal traceability system, considering regulatory uncertainty stands as a barrier to blockchain technology adoption (Sodhi and Hastig 2019).

2.6. Real Use-Case Implementation of Blockchain

Japan is one of the countries that implemented traceability systems across nations long before blockchain technology arose. The famous Japanese wagyu beef is traceable through the supply chain course (Heitzeberg 2017). The rise of blockchain technology provokes other companies in the beef supply chain to utilize it as a product traceability system to gain a competitive advantage. BeefChain and Genesis are the products developed to provide transparency for their partners and consumers (Cryptum 2019), (BlockApps 2021).

The Genesis blockchain allows users to track animal data such as health protocols, progress across the supply chain, and updates on the meat's current location (BlockApps 2021). It also uses smart contracts to validate transactions and provide a service for data flow customization between buyer and seller, which means the seller has options for sharing product credentials. Aside from the additional customization service, the BeefChain offers a similar service for its partners and consumers. The apparent difference is that Genesis is built on a private blockchain network, BlockApps STRATO (BlockApps 2021). In comparison, BeefChain develops a traceability solution atop the Cardano blockchain, a public blockchain (Hill 2020). The process transparency impacted by blockchain ensures the information integrity of beef originality to their consumers.

We can deduce that the wagyu beef mechanism as one real use case could be enhanced or even generalized to be implemented in a universal/broad supply chain. Regarding transparency, our model put on a halal aspect since other companies successfully implemented blockchain to trace their product.

3. Methodology

Based on the context of blockchain as an emerging technology, we deemed to conduct a study that thoroughly explored the blockchain-based supply chain solution. Due to the complex nature of the supply chain and limited study about blockchain use in halal terms, we interviewed stakeholders such as regulators and practitioners to gain a comprehensive insight into the use of blockchain on current business processes in the halal meat industry.

The current study uses a qualitative approach by observing and interviewing selected stakeholders in the slaughterhouse industry. We employ the modified research procedure from Rohaeni and Sutawidjaya (2020). The exploration of the literature review from the previous research paper to validate the phenomenon was also conducted to find the possibility of the proposed solution and identify the research gap. Then, we analyzed the real use case of blockchain implementation in the meat supply chain. We expect to gain insights for our proposed model from the already implemented blockchain solution, which tackles a similiar issue as in the current study. Next, we separately interviewed each stakeholder: a delegate from MUI, a retailer, and a slaughterhouse. The current study methodology triangulations are composed by the literature review, analyzing the real use case of blockchain implementation and interviews.

Our interview is arranged through teleconference application due to the COVID-19 pandemic occurrence. From the process, we collect insights into the operational process of the slaughterhouse industry, the process to determine the status of halal meat, and the mechanism of halal assurance for the public interest. We verified and scrutinized the business process in an interview session with the slaughterhouse and retail owner.

The collected data from the interview went through the coding and categorizing processes. We adopted several themes to construct the proposed blockchain-based traceability system model. Our confident hope is that the proposed model will change Indonesia's current halal supply chain to a better stage in the halal assurance system. For a clear understanding, the research procedure is in Figure 2. However, it is necessary to develop a decentralized application to implement the proposed model, which stakeholders, especially consumers, can freely access. Then, supportive actions from the government on a national scale can commence in the forms of regulations, education of on-chain stakeholders, and investment in the halal assurance system.

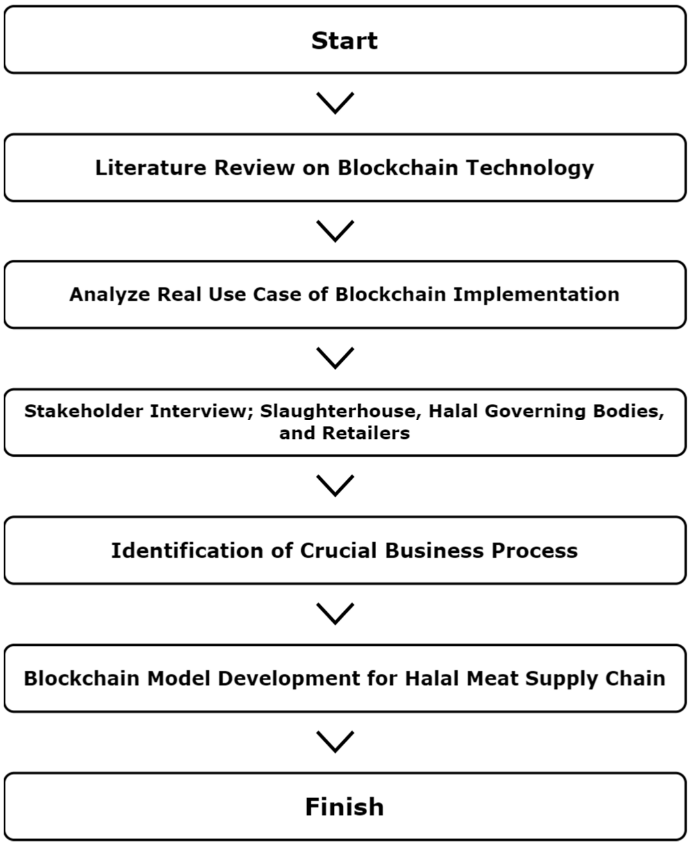

Figure 2. Research workflow.

4. Model Construction

Proposed Model

We found some critical information used to perform halal verification from the interviews with the halal supply chain stakeholders. These are:

1. Slaughterhouse's halal certificate.
2. Cattle inspection result document (before and after slaughter process).
3. Slaughterhouse's certified abattoir.
4. Slaughter method (stun/no stun).

From the business owner's perspective, halal assurance technology with a higher level of security consequently pushes slaughterhouses to invest in it. They believe that local government and MUI will eventually make specific regulations to put the technology into business practice. The findings are parallel with the study by Sander et al. (2018). The challenge of implementing blockchain technology comes from the stakeholder's business feasibility, traceability effectiveness, and impact on halal assurance along the supply chain. We construct a blockchain model based on the gathered insight to pursue a halal traceability system on the current supply chain.

The illustration in Figure 3 Visualizes our model to provide halal assurance on a specified halal supply chain with blockchain technology. There are seven types of nodes in the network to represent current supply chain stakeholders. The critical point of this model is to create transparency throughout the complex supply chain by integrating one another's stakeholders; thus, all network members can have a comprehensive meaning of product status by tracing it back upstream of the business process. The integration concurs from using a consistent data format in which its attributes can represent the halalness of the product. Each participant can see who is responsible for each activity on the network. Tracing a product's halal status can be narrowed to small batches, even each item. The mechanism acts as an opportunity to change the current business process and halal assurance activities.

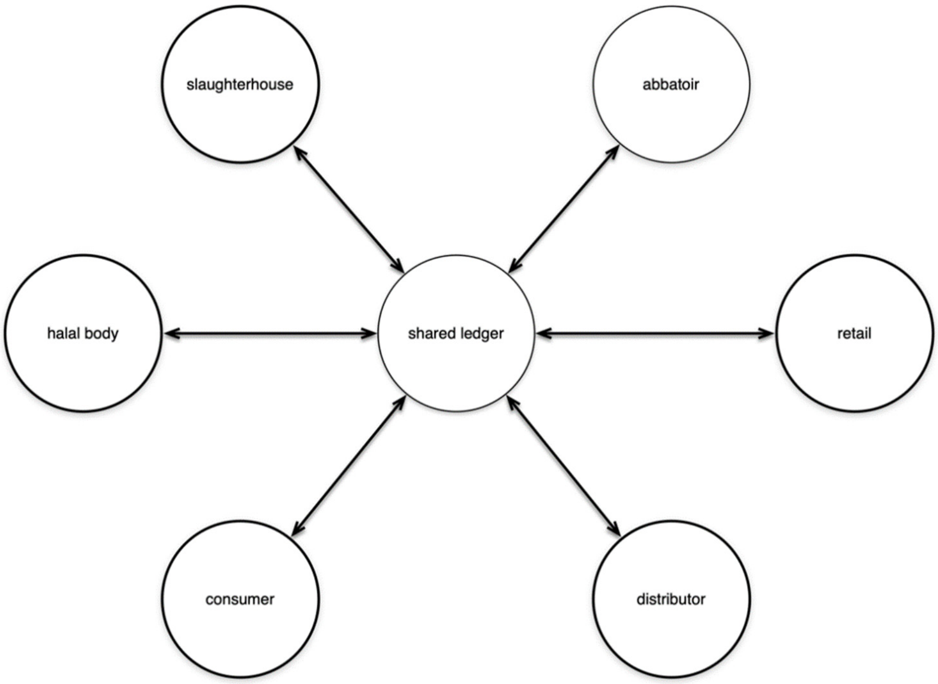

Figure 3. Proposed model.

Rejeb (2018), in the previous study, proposed a similar model. In the proposed model, there are farmer entities and farming activities; each livestock has a document stored in the blockchain network. The farmer creates the first block on a blockchain network when the cattle are harvested and delivered to the slaughterhouse facility. The author considers it would be more efficient if the slaughterhouse entities were to build the first block; the reason is that there are more halal critical points in slaughterhouses. Five out of ten halal essential control points occur during the slaughtering phase. Therefore, when the slaughterhouses make the first block/genesis block, the verifying process from halal bodies to determine halal meat status would be more efficient.

In Rejeb's model, the farmer entity stores information about each livestock, including the background environment of farming. Our model can solve such inefficiency without generating a genesis block in the farming stage by utilizing an IPFS and putting the document ID on the genesis block. The use of an IPFS guarantees the integrity of the content since each file stored has a unique hash (Casino et al. 2020). Our proposed model combines IoT as data entry technology to record the data distributed on the blockchain network. The method was to avoid human error in data collection in the field.

5. Result and Discussion

In this section, we describe the resulted proposed model and lay the ground to discuss the model. The following discussion is based on the result of the literature review, interviews with the meat halal supply chain stakeholders, and analyzing the real use case of blockchain implementation. The discussion's content focused on how the proposed model should be built—first, a discussion on stakeholders and the composition of the proposed traceability system. Then, the discussion carries on to the separate process of the proposed model, the related physical activities, and activities on the blockchain network. The final part discusses which blockchain platform to choose based on the prioritized criteria.

5.1. System Design

The first element to discuss is the proposed system design; therefore, stakeholders can understand how to contribute to the halal supply chain. The proposed system involved actors such as:

1. Slaughterhouse: Manage slaughtering process based on sharia law and pack and tag the meat with an IoT device.
2. Abattoir: Perform slaughter process.
3. Halal body: Verify and give a digital halal pass to the meat.
4. Distributor: Perform delivery of the meat from slaughterhouse to specific retailer.
5. Retailer: Mainly sell the meat to a consumer; it can be small stores or supermarket chains with halal certificates.
6. Consumer: Decides to buy halal meat with a desired halal assurance.

We propose a layered system design to separate physical-related action and digital-related action. We use blockchain as a public untampered database for the digital process and IoT devices as data entry technology. We consider this an efficient move to ensure the data credibility along the chain. Supporting this system as the main modules are:

1. IoT device: A component to collect data directly from the physical process along the chain.
2. API: Serve as a gateway to write and read data directly from the system based on the roles of the stakeholder while integrating them into the blockchain environment.
3. Blockchain: The central part of the system, with a smart contract, provides automation based on predefined events.

The system needs to be preconditioned, demanding all stakeholders register to operate inside the blockchain environment. This model is called permissioned or private blockchain. The operation inside the closed ecosystem is to guarantee that all transactions work in order. The mechanism ensures to reduce security threats and data integrity problems posed by unknown actors. The system will, contrarily, be different from the current practice of halal assurance through the website and centralized manner. The most important parts of the system that need to be executed are the agreement on the Critical Tracking Event (CTE) and Key Data Element (KDE) (Bhatt et al. 2013). In the designed system, the CTE is shown in the next section (*off-chain process*), and the KDE is discussed as the proposed block structure in Section 5.3 (*on-chain process*). For the real use case of blockchain implementation in the meat supply chain, we analyzed BeefChain and Genesis, which were launched several years before this study took place. From these cases, we deduce several key points, which are:

1. The designed system ought to trace assets to their origin with decent information.
2. The benefit of the system can be perceived by all participants.
3. There are options to develop the model in private blockchain or standard/public blockchain.

5.2. Off-Chain Process

As the designed system operates, there is physical-related work along the supply chain—such as slaughtering, packing, distribution, etc. We call it the *off-chain process*, which distinguishes activities from blockchain-related ones. We summarize the *off-chain* process into some stages, which are:

1. Pre-distribution: All activities from slaughtering, packing, and tagging the meat with code such as RFID.
2. Distribution: Logistics-related activities such as scanning the packed meat to ensure a halal pass and delivering it to the designated retailers.
3. Post-distribution: Activities by retailers to represent the meat in sale sections, and consumers scan the tagged meat.

Throughout the off-chain process in the supply chain, the meat from the slaughtered cattle would be distributed physically from the slaughterhouse to the end consumer. The illustrated off-chain process is in Figure 4. End consumers (users) in the illustration can verify a product's halal status by simply accessing the network containing freshly updated information about each product and tracing it back to the manufacturer who distributed it, proving the halal product assurance. The process of users accessing data can be conducted either from a web page or a Dapp.

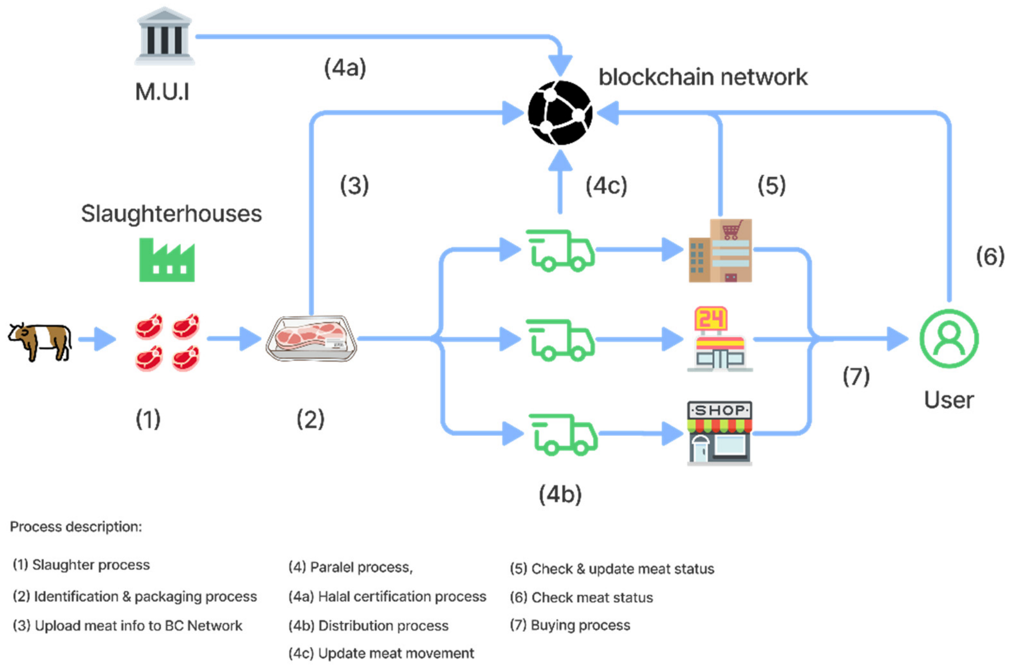

Figure 4. Proposed off-chain process.

For retailers, the decision to implement blockchain in their business is at their own discretion. Still, when they adopt blockchain, retailers need to educate their consumers on the benefit of the technology, since public understanding regarding either implication or function of blockchain technology is presently lacking (Garaus and Treiblmaier 2021). Additionally, the failure to educate consumers may lead to negative thoughts relating to the technology (Astill et al. 2019).

5.3. On-Chain Process

On the other hand, in a parallel way, there are blockchain-related activities. We consider these as an on-chain processes. The core of this process is to provide untampered data on the blockchain database with the help of smart contracts along the way.

Our idea of the process is represented on Figure 5. The physical meat is labeled at the slaughterhouse; each meat from the same cattle has a unique meat ID. Then, the slaughterhouse uploads the unique meat ID data to the blockchain network. The first mechanism is the document verification process by MUI to assess the halal status of the meat. If the meat is halal, then MUI gives the halal stamp, if not, it will not receive MUI halal stamp and the transaction will not continue. MUI writes an IPFS address on the blocks with MUI's halal stamp; the contents of the IPFS are halal certificates specified with meat IDs. With this mechanism, the halal assurance is accurately defined on each meat.

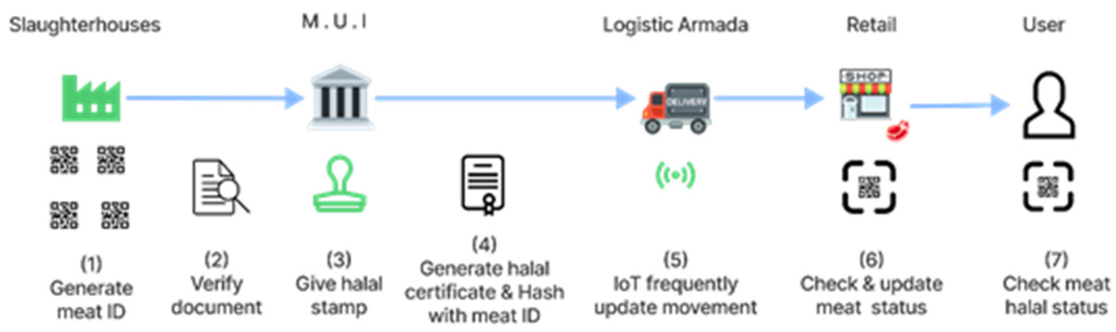

Figure 5. Proposed On-Chain Process.

The next block creation is in the distribution stage; the meat carrier changes from MUI to distributor. The block is frequently updated based on the movement from the logistic armada until it arrives at a particular retailer. The retailer then scans the QR code to check the meat status and update the situation by giving the store's name. Lastly, the end consumer (user) scans the QR code on the meat packaging to see the quality of the meat. Information such as slaughterhouse and abattoir who performed the process, MUI halal certificate, and the logistic company that dealt with the meat appear on the status. Such information is needed for consumers to trace back to upstream stakeholders and ensure the product received a halal certificate from the MUI.

Figure 6 illustrates the constructed block and the data inside it on the blockchain network. Its attributes inform stakeholders of where this meat came from and which cow and slaughterhouse are in charge of slaughtering. Consumers can obtain this detailed information when the meat reaches the retailer by scanning the QR code with specific applications.

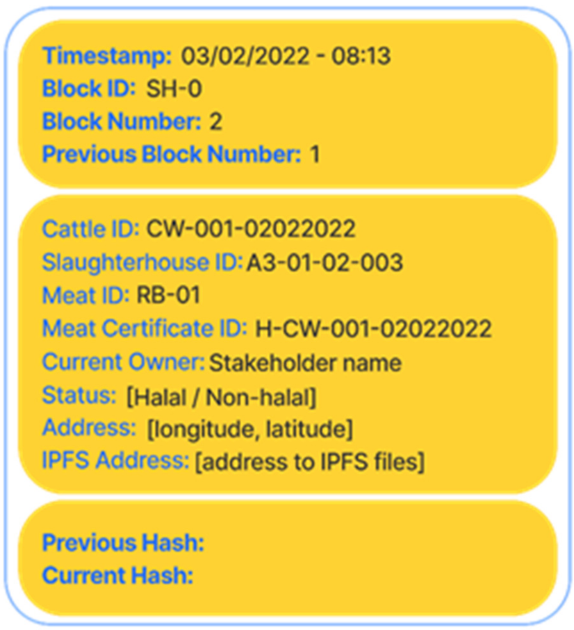

Figure 6. Proposed block structure.

Each network participant would use this block format to maintain consistency, another characteristic of blockchain technology. Each block contains an identity represented with a 'Block ID' and 'Block Number'; the 'Timestamp' attribute shows when the block is added to the blockchain network. 'Cattle ID' acts as a data attribute to identify the slaughtered cattle; the 'Slaughterhouse ID' gives insight into which slaughterhouse performed the slaughter.

Then, the 'Meat ID' attribute is the current meat identity on the blockchain network; the information on it would be the type of the meat and the serial number following it. At the same time, the 'Meat Certificate ID' gives information on MUI halal stamps.

The 'Current Owner' attribute represents which participants handle the meat in the current process; data on this attribute change frequently. The 'Status' attribute informs about the meat halalness when carried by stakeholders; if the status is not halal, the transaction is stopped and the physical meat is removed from the supply chain. The 'IPFS Address' attribute reveals the link where the halal certificate of the facility and the meat is stored in the IPFS, a cloud storage characteristic in the blockchain. Additionally, the hash acts as a cryptography linkage to the previous and next block to prevent the data from being tampered with.

The overall process means that the halal slaughterhouse performed the slaughtering process, and they would upload specific documents to an IPFS. MUI can access the IPFS to determine and fill the 'Certificate ID' and 'Status' attributes. If the 'Status' is Halal, it means the meat comes from slaughtered cattle with halal procedures, and every meat that comes from the cattle also inherits halal status. The proposed model narrowed the halal assurance to a level of individual meat or small batches.

A granularity of information is a condition in which a piece of information is divided into an appropriate level of detail. It is beneficial for the data retrieval process, which sometimes needs only certain parts from the whole picture. The on-chain process provides information granularity from the specified data attributes and the concept of a chained block of data in the blockchain concept, where a chain of meat information is divided into several blocks depending on the steps of the off-chain process. This way, the information is stored in the blockchain network but still has an appropriate level of detail in each block.

5.4. Development of the Proposed Model

Before implementing the proposed model, one last consideration is to decide the platform on which the blockchain network development will be performed. We only considered the proof-of-stake (PoS) consensus mechanism rather than proof-of-work (PoW) since we are looking for less resource-demanding processing and a friendly environmental ecosystem. System requirements must be suitable for the blockchain feature feasibility and prioritize criteria. The choices ordered from the highest priority are:

1. The smart contract capabilities to automatically execute the whole supply chain process.
2. The transaction speed, meaning the time needed to write the record into the ledger, which includes time to validate the transaction and propagate the latest ledger update to all nodes in the network.
3. The transaction cost: the de facto choice to build a Dapp on top of a blockchain network is by using the Ethereum network; however, since there are a lot of demands on this network, the transaction cost becomes expensive. Thus, we prefer to use the Layer 2 solution, which is more scalable and cheaper.

Though there are many platform choices for developing a blockchain-based system, this study highlights the most suitable and state-of-the-art at the time of this writing in Table 1 to make the discussion concise.

On the final application, we might expect more data attributes in the block structure than we currently propose, as in Figure 6. We also presume that in the early implementation phase, the number of transactions will be lower than the standard blockchain capabilities, as mentioned by Huang and Huang (2020). Nevertheless, we must prepare that the application can handle large-scale transactions, or what we call scalability features. As the number and type of stakeholders grow, we expect to increase data records and retrieval, not to mention the need for a real-time meat status report.

Table 1. Blockchain platform comparison.

Feature	Ethereum	Ripple	Cardano	Cosmos	Polkadot	Elrond	Avalanche	Solana
Cryptocurrency	ETH	XRP	ADA	ATOM	DOT	EGLD	AVAX	SOL
Block Creation Time (seconds)	14	4	20	7	6	6	3	8
Transaction per Second (TPS)	5	1500	250	1420	1000	5000	1000–4500	13,000
Transaction Fee [1]	USD 4	<USD 1	<USD 1	<USD 1	<USD 1	<USD 1	<USD 1	<USD 1
Distributed Cloud Storage	Yes	No	No	Yes	No	No	No	No
Decentralized Apps (Dapps)	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes

[1] Transaction fee is based on December 2021.

There are several node types involved in the process. The node could be the stakeholder or the dedicated computer system involved in the data record process, transaction validation, and propagation of the latest update to the ledger. The first type is undoubtedly the stakeholders to publish the data. The second type is the stakeholders to validate transactions on the network. The last type is stakeholders to record all the data, such as retailers and distributors. At the same time, consumers (users) may access the records in real-time.

Based on the analysis of the blockchain platform comparative features in Table 1 and the halal supply chain characteristics, we recommend developing the proposed model using the Avalanche platform. The reasons are:

1. It has the fastest block creation speed, and it has transaction processes up to 4500 transactions per second, secondary to Solana.
2. It is a much cheaper transaction cost compared with the de facto Ethereum network.
3. It can support the development of permissioned blockchain, which requires that each actor/stakeholder obtain the license to operate inside the network. This governance can also limit the right of each stakeholder on the go.
4. It is suitable to support different types of stakeholders, including miners or validators, to validate a chosen transaction.

To develop such a crucial system on an open-source platform or build our own blockchain from scratch, we may consider a few things. First, there might be a possibility of ‘hidden cost’, which commonly exists on the open-source platform. When we build a system atop an open-source platform, it is probable for an attacker to gain advantage of it. It is highly likely for them to create an ‘attack’ from the same platform. Second, the model is designed for Indonesia’s supply chain, making it important for the data to be kept inside Indonesia’s domain. A self-designed blockchain network allows Indonesia to gain firm control over sensitive information through data sovereignty. Therefore, it is preferable to build our own blockchain network. Still, our own blockchain is plausible to underperform compared with the existing open-source platform.

6. Conclusions

We propose this model to be the foundation for enhancing the real-time traceability of Indonesia’s halal supply chain system. The model involves halal bodies, slaughterhouses, abattoirs, retailers, distributors, and consumers. Each stakeholder can trace the asset (halal meat) on blockchain networks that represent the physical status of the asset. The primary use case of the model is to enable transparency, thus providing tracing ability for the asset movement in the supply chain line. The consumers gain advantages, first tracing back to whom are involved in the distribution process of each asset. Second, consumers are capable of checking whether the asset has halal status or not, as assured by the official halal body. The advantage for producers, distributors, and retailers is that the system forms data integration along the supply chain—minimalizing information asymmetry, which increases trust between them.

This research covers the general practice of slaughterhouses in Indonesia. Hence, we can generalize the model to become a national standard for the halal meat industry. The enhanced model in the future is based on the result of the current model implementation. Therefore, future research needs to be conducted by prototyping the model, analyzing the transaction cost (blockchain operational cost), and testing the feasibility, viability, and desirability. The model in this study serves as an improvement insight for the government and business owners to decide on investment to reach a better halal supply chain in Indonesia.

For managerial implications, the model implementation will strengthen the promise of halal assurance for the market because it provides real-time assurance. The model also enhances the certification coverage to small batches or individual levels. Thus, the halal bodies may achieve time and workforce efficiency on this matter, eventually providing a better service for the public. Our model gives comfort to the public, especially the Muslim community in Indonesia, since the model is designed specifically for Indonesian meat and provides more information granularity than the current system.

The study serves as a reference for blockchain research and the supply chain domain in the professional and academic domains. Policymakers, system designers, and developers could adopt the model. We anticipate new blockchain use-case ideas for various traceability matters. The humanitarian fundraising, crowdsourcing mechanism, and talent reputation management could benefit from similar traceability approaches. Thus, we hope our study could raise public awareness, and that eventually blockchain will become widely adopted. As for a theoretical contribution, this study presents how to construct a blockchain traceability model and an off-chain/on-chain mechanism suited to Indonesia's conditions.

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