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RESEARCH PAPER

FMEA for Blockchain Design for Food Safety and Halal Risk Mitigation in Meat Supply Chain

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ABSTRACT
This research discusses the application of the Failure Mode and Effect Analysis (FMEA) method in designing a blockchain system for mitigating food safety and halal risks in the beef supply chain. The complexity of the meat supply chain involving various parties increasing the risk of contamination and changes in the halal status of the meat. This research aims to identify food safety and halal risks, prioritise the risks, and design blockchain-based mitigation solutions. Blockchain was chosen for its advantages in providing high transparency and accountability, enabling real-time tracking at every stage of the supply chain. The research results show that most of the risks in the meat supply chain fall into the low category, but there are some critical medium risks, especially related to the slaughtering process. The proposed blockchain design includes product traceability features, halal certification, temperature monitoring, and smart contracts to ensure automatic validation of food safety and halal compliance. The implementation of this blockchain is expected to increase consumer trust in meat products, reduce the risk of contamination, and strengthen accountability throughout the meat supply chain.

KEYWORDS: Meat supply chains; Food safety; Halal; Blockchain; FMEA.

1. Introduction

The meat supply chain is one of the components in the food industry that is highly vulnerable to the risks of food safety and halal contamination [1] is because meat has a complex supply chain involving many parties, such as farmers, slaughterhouses, processors,distributors, and retailers [2]. This complexity results in significant challenges for the meat supply chain to maintain compliance with food safety and halal standards. The challenges faced include supervision and quality monitoring, halal label counterfeiting, contamination, and product traceability [3]. Each party in the supply chain must be responsible for maintaining the quality of the meat based on food safety and halal standards [4].When not managed properly by the company, these challenges will lead to consumer dissatisfaction because the products received are not safe and halal for consumption [5].

Currently, food safety has become a special concern in society due to the increasing incidence of food poisoning. The occurrence of food poisoning is triggered by food that has been contaminated with pathogenic bacteria or other viruses. [6]. The number of food poisoning cases varies over time, and there are no specific rules regarding this [7]. WHO data shows that 1 in 10 people worldwide will fall ill after consuming contaminated food, and 420,000 people die each year [8]. On the other hand, for Muslims, consuming halal meat is an obligation. Therefore, before making a purchase transaction, ensuring that the meat being bought is halal is the top priority. In recent decades, there has been an increase in demand for halal products, leading to the creation of a large and growing global halal market [9]. In reality, due to economic motives, there have been several cases of halal meat fraud, which originated from non-halal meat (dog and

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pig) in both Muslim and non-Muslim countries [10].

However, consumers have not been receiving transparent information about the condition of the meat throughout the supply chain, leading to consumer hesitation in making transactions. Risks in the supply chain can originate from suppliers, processing companies, distributors, or modes of transportation. [11][12]. The potential risk of changes in the safety and halal status of meat during the supply chain is a source of consumer doubt in transactions. That doubt also poses a risk to business operations and legal matters for entrepreneurs.

Blockchain is a potential solution to address this issue. Blockchain has the advantage of being able to record every transaction permanently and validated so that it cannot be changed [13]. Moreover, blockchain offers the aspects needed in the supply chain, namely transparency and accountability [14]. Transparency and traceability of food (meat) in the supply chain play an important role in ensuring high-quality and safe food [15]. With blockchain, the journey of meat at every stage in the supply chain can be recorded and traced in real time.

The gap in this research is the unavailability of a blockchain design that can ensure food safety and halal in the meat supply chain. Therefore, this article discusses the design of a blockchain for the meat supply chain that can be used to mitigate food safety and halal risks. This is important so that consumers have the assurance that the meat products they purchase are guaranteed to be safe and halal, making them safe for consumption. The approach used in designing a blockchain for the meat supply chain based on food safety and halal is the Failure Mode Effect Analysis (FMEA) method. Utilising FMEA results to design this blockchain is the novelty of this article. The main contribution is the availability of a blockchain model that is able to guarantee data transparency so as to ensure consumer confidence that the products purchased and consumed have met food safety and halal standards. The objective of this research is (1) to identify potential food safety and halal risks in the meat supply chain, (2) to prioritise the risks, and (3) to develop risk mitigation through blockchain design.

2. Literature Review

2.1. Food safety risk

Food safety is a condition that ensures food is safe for consumption, free from physical, biological, or chemical contamination. In general, food can become contaminated at any time through various activities, such as slaughtering or harvesting, processing, storage, distribution, transportation, and preparation [16]. Food safety risk refers to anything that poses a threat to human health and originates from the food consumed [17]. Food safety risk experiences dynamic development along with human growth due to various influences, such as natural conditions and the environment[18]. Food safety risk has two dimensions, namely the likelihood of the risk occurring and the impact generated by that risk. The character of each dimension is influenced by the conditions of the demographic group [19].

2.2. Halal risk

Halal risk is the risk that occurs due to contamination from halal materials or products. This contamination can happen due to the mixing of halal and non-halal products in warehouses, using the same equipment and production areas to process halal and non-halal products, and the use of raw materials or food additives that have not been halal certified [20]. Based on the aspect of halal integrity, there are three main risks that need to be addressed immediately to prevent the change of halal status to non-halal, namely partnership risk, transportation risk, and unskilled worker risk [21]. Therefore, to prevent the risk of halal status changing to non-halal in meat, policies regarding the stunning equipment used in slaughterhouses and the availability of halal policies for transportation companies and companies [22].

2.3. Meat supply chain

The supply chain is a series of processes that meat goes through from the farm to the consumer. There are two types of sectors in the beef supply chain, namely the upstream sector and the downstream sector [23]. The upstream sector shows the journey of live cattle to the slaughterhouse. The downstream sector shows the processing of beef into derivative products. The meat supply chain can improve its competitiveness and innovation through the institutional environment, business capacity, and consumer behaviour [24]. The complexity of the supply chain is determined by the product produced. The supply chain for fresh meat is different from the supply chain for processed meat products. The fresh meat supply chain consists of farmers, slaughterhouses, distributors, and retailers [25]. Meanwhile, the processed meat supply chain consists of importers, companies, distributors and retailers, and consumen. The most prominent aspect of the processed meat product supply chain is the complexity at the company level. The more complex processed meat products are, the more activities are carried out in the processing/production process at the company.

2.4. Blockchain

Blockchain is a technology consisting of a series of blocks to be used to make digital records in a decentralised, secure, and immutable manner [26]. Transactions recorded in each block have been verified and confirmed by interested parties. That is what makes blockchain can be used for various purposes of tracking various kinds of data, such as finance and costs, supply chains, and food safety systems [27][28][29]. In addition, blockchain has the potential to be used in geospatial data sharing, construction management, and corporate sustainability [30][31][32]. Blockchain has specific characteristics, namely decentralisation, trust, persistency, anonymity, and auditability [33]. However, there are barriers to blockchain utilisation, which are related to institutional and regulatory, social and cultural, economic/financial and marketing, and technical [34]. In its implementation, the utilisation of blockchain provides value addition so that consumers have important implications for marketing [35]. The development of blockchain is geared to be coupled with AI and expertise for clinical trials, and the role of humans cannot be eliminated in developing a trustworthy blockchain architecture [36][37].

2.5. FMEA

Failure Mode Effect Analysis (FMEA) is one of the effective and efficient risk measurement methods to be implemented in various fields. In the field of occupational safety, FMEA is used for safety improvement in the ammonia deviation process [38]. In construction, FMEA is used to identify risks that occur during the project cycle phase, thereby improving project safety and reliability [39]. Other fields that use FMEA to identify risks are college laboratories, hospitals, ship berthing, and the paper industry [40][41][42][43]. The advantage of FMEA is that it is able to analyse and identify failures to improve the reliability of products, processes, and systems [44]. Another advantage is that FMEA is a prospective and effective risk evaluation approach to improve process safety so as to improve performance and profitability [45][46] FMEA is processed based on assessments made by a network of experts in risk management [46]. Compared to RCA (Root Cause Analysis), FMEA is more proactive in identifying and managing risks so that preventive measures can be taken to minimize or eliminate risks. When compared to FTA (Fault Tree Analysis), FMEA provides a more structured and systematic way of working for risk identification, not only focusing on causal relationships.

3. Methods

This research was conducted with the object of research being the beef supply chain in the East Java region (Indonesia). The research was conducted in June–July 2024. This research was conducted in two stages, namely risk measurement and risk mitigation.

Stage 1: Risk Measurement with FMEA

At this stage, data collection was carried out using interviews and questionnaires. Interviews were conducted with actors involved in the meat supply chain, namely: farmers, companies, distributors, and retailers. Interviews are used to find out the activities carried out by supply chain actors. Questionnaires were used to conduct a risk assessment of the meat supply chain. Risks were identified based on food safety and halal. The assessment was conducted by experts who understand the processes and risks in the meat supply chain. The questionnaire was designed to assess O (occurance), S (severity), and D (detection) [45]. O indicates the likelihood or frequency of failure. S is the consequence (impact) if a failure occurs. D is the possibility of detecting the failure. The score used for the O, S, and D assessments is 1-10 with details:

Tab. 1. O, S, and D scale

Scale		Definition
1-10	O	The higher the rating scale, the higher the frequency of failures.
	S	The higher the rating scale, the greater the impact of the failure.
	D	The higher the rating scale, the higher the detection of failures.

Furthermore, data processing is carried out using the FMEA method, namely by calculating the RPN (Risk Priority Number) value with the following formulation:

RPN = S x O x D

The results of the RPN value calculation can be classified as low risk (RPN < 70), moderate risk (70 ≤ RPN < 200), high risk (200 ≤ RPN < 400), and extremely high risk (RPN > 400).

Stage 2: Risk Mitigation

Risk mitigation is used to avoid the occurrence of risks identified in the previous stage. In this risk mitigation stage, blockchain features will be designed to avoid food safety and halal contamination in the meat supply chain. Blockchain was chosen because of its ability to store data permanently and irreversibly so that it cannot be falsified [47]. In this research, the blockchain is structured in the following stages: 1) selection of blockchain type; 2) design of blockchain features; and 3) design of blockchain model/blockchain architecture design.

4. Result amd Discussion

4.1. Food safety risk

Food safety is a condition that ensures food is safe for consumption, free from physical, biological, or chemical contamination. In general, food can become contaminated at any time through various activities, such as slaughtering or harvesting, processing, storage, distribution, transportation, and preparation [16]. Food safety risk refers to anything that poses a threat to human health and originates from the food consumed [17]. Food safety risk experiences dynamic development along with human growth due to various influences, such as natural conditions and the environment [18]. Food safety risk has two dimensions, namely the likelihood of the risk occurring and the impact generated by that risk. The character of each dimension is influenced by the conditions of the demographic group [19].

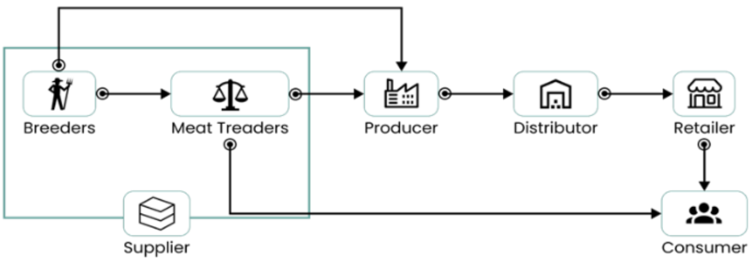

Fig. 1. Meat supply chain

Fig 1 shows the meat supply chain. In the figure, there are two types of suppliers: farmers and meat traders. The slaughtering of cattle can be done by farmers, meat traders, or companies, according to the agreement of both parties. Furthermore, the beef that has been slaughtered is processed by processing and manufacturing companies into processed products. Products from manufacturers are marketed through a network of distributors and retailers to consumers. The next research result is the identification of food safety and halal for each actor in the supply chain as follows:

Tab. 1. Food safety and halal for suppliers

Risk	Ideal Condition	
	Food Safety	Halal
Animal condition	Healthy, does not contain zoonotic diseases	Derived from living animals
Cow food	Beef food is free from harmful ingredients, such as chemicals, pesticides, heavy metals, or pathogenic microorganisms.	Cow food does not contain haram ingredients.
Drinking water	Drinking water does not contain microbial contamination or harmful substances.	Drinking water is not contaminated with Najis or haram materials.
Slaughter labor	• Healthy, free from infectious diseases • Understand slaughtering methods. • Certificate of slaughter training	• Islam • Obedient worship • Read bismillah • Have a halal slaughterer training certificate
Slaughter equipment	The knife used should be clean, not contaminated with bacteria, etc.	• Sharp blade • Not contaminated with unclean / haram substances

Transportation tools	Transportation equipment hygiene	• Not mixed with non-halal products • Transportation providers have halal certificates.
Storage	• Room temperature • Room cleanliness	Not mixed with non-halal products

Table 1 shows the ideal conditions for each food safety and halal risk indicator for suppliers.

Tab. 2. Food safety and halal for manufacturer

Risk	Ideal Condition	
	Food Safety	Halal
Raw material	No chemical, physical, or biological contamination	Has a halal certificate or is included in the positive list
Production equipment	Hygienic	Especially for halal products
Warehouse irregularities	• Controlled room temperature • Storage warehouse cleanliness	Special storage warehouse for halal products
Product testing	Product lab tests to prove free of chemical, physical, and biological contamination	Lab testing of products to prove they are free of haram ingredients
Recording and documentation	Recording of material, product and distribution utilization	Recording the inspection of ingredients by entering the halal indicator (no halal certificate)
Non-compliant product recall	Products detected to have biological, chemical, and physical contamination	Products that are detected to be contaminated with non-halal ingredients or products
Employee training	Food safety training	Halal training

Table 2 shows the ideal conditions for each food safety and halal risk indicator for manufacture.

Tab. 3. Food safety and halal for distributor/ retail

Risk	Ideal Condition	
	Food Safety	Halal
Storage area	The storage area is clean from chemical, physical, and biological contamination and hazardous materials that can contaminate the product.	Dedicated storage for halal products
Transportation Vehicle	Using clean vehicles designed to maintain food safety	Using vehicles that are clean, food-safe, and specialised for transporting halal products
Product supervision	Recording product expiration time	Recording halal certificate number
Traceability system	A system is in place to trace the origin and destination of product distribution	A system is in place to trace the origin and destination of product distribution.

Table 3 shows the ideal conditions for each food safety and halal risk indicator for distributor/ retail.

Based on the ideal conditions of food safety and halal aspects for the meat supply chain (tables 1, 2, and 3), the identified risks and RPN are as follows:

Tab. 4. Risk identification in meat supply chain based on food safety and halal

Supplier			
Risk/ Code	Potential failure	Effect	Couse
Animal Condition (RS_1)	• Failure to maintain animal conditions resulting in zoonotic diseases	• Consumen health • Consumer trust	Farmers' lack of understanding of the

	• Failure to maintain the health of the animal so that it dies before slaughter.		animal husbandry system
Cattle feed (RS_2)	• Failure in feeding so that the food provided contains non-halal ingredients • Failure to adjust nutrient composition. • Failure to keep food away so that food is contaminated with chemicals or pathogens	• Its halal status is in doubt. • Mortality in cattle • Decreased meat quality • Decrease in meat selling value	• Inappropriate food selection • Lack of understanding about nutrition • Unclean environment
Drinking water (RS_3)	• Failure due to drinking water contaminated with impurities or chemicals/pathogens. • Failure due to improper drinking water source		• Drinking water sources are polluted. • Drinking water reservoirs are not clean.
Slaughter labor (RS_4)	• Failure of slaughter procedures • Failure of slaughterer skills • Failure of slaughterer hygiene	• Change in meat status to non-halal • The occurrence of bacterial contamination or other substances that can poison consumers	• Lack of training for slaughter personnel • Limited slaughter time • Tight production schedule
Slaughter equipment (RS_5)	Failure on equipment used that is not sharp and not clean		• Staff lack understanding of equipment requirements for slaughtering • Poor equipment quality • Weak equipment maintenance system
Transportation tools (RS_6) and storage (RS_7)	• Failure of cross-contamination with non-halal ingredients / products • Failure at unstable room temperature • Failure in vehicle conditions / less clean storage space • Failure in physical contamination of meat • Failure to use inappropriate packaging	• Change in status of meat to non-halal • Decrease in meat quality • Financial loss • Decreased consumer confidence	• Low labor skills • Weak vehicle maintenance system
	Manufacture		
Risk/ Code	Potential failure	Effect	Couse
Raw material (RM_1)	• Failure in the use of non-halal raw materials • Failure of cross-contamination with non-halal ingredients, bacteria or pathogens. • Failure in the addition of unsafe and non-halal additives	• Change of halal status to non-halal • Product recall • Decrease in product quality • Decrease in the number of products sold • Sanctions from interested parties	• Weak halal inspection of raw materials • Non-compliance with food safety procedures • Weak performance of raw material suppliers
Production equipment (RM_2) Warehouse irregularities (RM_3)	• Failure on cross-contamination with non-halal products • Failure of unstable storage room temperature	• Halal to non-halal status change • Physical, chemical and biological contamination	• Weak control system for production equipment and storage warehouse.

	• Failure of cleanliness of production equipment and storage space is not maintained.	• Decrease in product quality	• Weak labor performance in equipment and warehouse storage
Product testing (RM_4)	• Failure of non-comprehensive test types • Failure of tests that do not comply with food safety and halal standards • Failure of invalid test results • Failure of testing not in accordance with procedures	• Change of halal status to non-halal • Decrease in product quality • Product recall	• Non-standard/uncalibrated testing equipment. • Weak test procedures • Weak ability of workers who conduct tests
Recording and documentations (RM_5)	• Failure of negligence in record keeping • Failure of incomplete and valid documentation • Failure to have an integrated monitoring system	• Difficulty in guaranteeing safe and halal products • Difficulties when there is a product recall • Difficulty in tracing data in the event of contamination	• Weak recording and documentation system • Inconsistency in recording and documentation
Non-compliant product recall (RM_6)	• Product recall delay failure • Failure of misidentification of recalled products • Failure to reach the distribution of the recalled product • Failure in communication with consumers	• Risk to consumer health • Decreased consumer confidence • Violating halal standards	• Weak product recall procedures • Weak internal audit system • Weak supervision of product recalls.
Employee training (RM_7)	• Failure of employees to understand food safety and halal standards • Failure to update training materials • -Failure to maintain consistency in training implementation	• Products are not safe and halal for consumption • Violation of food safety and halal standards • Decrease in consumer confidence	• Lack of budget for employee training • Weak employee training procedures • Lack of monitoring and evaluation of employee training • Work culture that does not support employee training
Distributor/ Retail			
Risk/ Code	Potensi Kegagalan	Potensial Efek	Penyebab
Storage area (RD_1)/ (RR_1)	• Failure on cross-contamination with non-halal products • Failure of unstable storage room temperature • Failure of storage room cleanliness is not maintained.	• Halal to non-halal status change • Physical, chemical and biological contamination • Decrease in product quality	• Weak control system for the storage warehouse. • Weak labor performance in the storage warehouse
Transportation Vehicle (RD_2)/ (RR_2)	▪ Failure of cross-contamination with non-halal ingredients / products • Failure at unstable room temperature • Failure in less clean vehicle conditions • Failure in physical contamination of meat • Failure in the use of inappropriate packaging	• Change in status of meat to non-halal • Decrease in meat quality • Financial loss • Decreased consumer confidence	• Low labor skills • Weak vehicle maintenance system

Product supervision (RD_3)/ (RR_3)	• Failure in critical stage control • Failure in product control consistency • Failure of inappropriate product monitoring equipment	• Occurrence of physical, chemical and biological contamination • Change of halal status to non-halal • Decreased consumer confidence • Product recall	• Weak resources for product monitoring • Weak product monitoring procedures • Lack of product monitoring training for employees • Product monitoring technology is not updated
Traceability system (RD_4)/ (RR_4)	• Failure to trace raw materials, processes, distribution systems • Failure to document traceability data (incomplete) • Failure to identify products in the supply chain • Failure to keep product history	• Product contamination is less traceable • Delays in recalling contaminated products • Inefficiency in product recall • Decreased consumer confidence	• Weak integrated traceability system • Lack of technology utilization for traceability system • No synchronization with third parties yet

Based on the risk identification, risk measurement is then carried out by determining the RPN value for each type of risk. The results of risk measurement are as shown in Table 5 below:

Tab. 5. Risk priority number (RPN) meat supply chain

Risk/Code	O	S	D	RPN	Status
RS_1	5	6	3	90	Moderate risk
RS_2	3	3	3	27	Low risk
RS_3	4	5	3	60	Low risk
RS_4	5	7	4	140	Moderate risk
RS_5	5	5	4	100	Moderate risk
RS_6	3	4	4	48	Low risk
RS_7	4	3	3	36	Low risk
RM_1	4	6	2	48	Low risk
RM_2	3	5	3	45	Low risk
RM_3	4	5	3	60	Low risk
RM_4	3	3	4	36	Low risk
RM_5	4	6	4	96	Moderate risk
RM_6	4	4	4	64	Low risk
RM_7	4	4	3	48	Low risk
RD_1	4	4	4	64	Low risk
RD_2	5	3	3	45	Low risk
RD_3	4	4	5	80	Moderate risk
RD_4	4	4	5	80	Moderate risk
RR_1	4	3	3	36	Low risk
RR_2	5	4	3	60	Low risk
RR_3	4	4	4	64	Low risk
RR_4	5	5	5	125	Moderate risk

Table 5 shows the RPN value for each risk in the meat supply chain.

The results show that there are two types of risks in the meat supply chain, namely low risk and moderate risk (Fig 2).

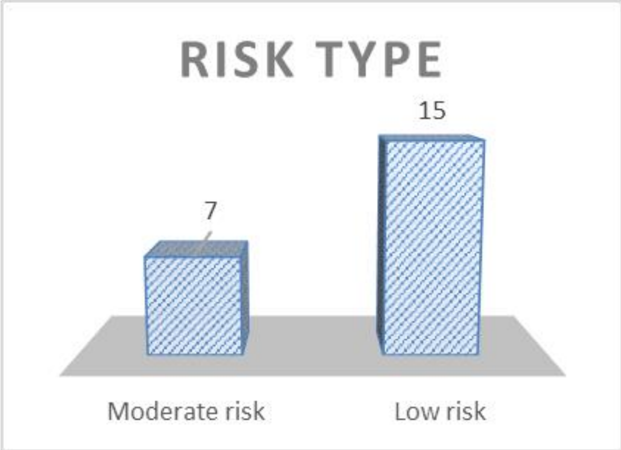

Fig. 2. Risk type

Most of the risks (15 risks) have a low risk type, and 7 risks have a moderate risk type. Of all the risks, the highest RPN value is found in RS4, which is slaughter labour. Slaughtering activities are a critical point in the meat supply chain. In the halal standard procedure, slaughtering provisions are found in slaughter personnel and slaughter equipment with ideal conditions as described in Table 1.

4.2. Risk mitigation: blockchain

Food safety is a condition that ensures food is safe for consumption, free from physical, biological, or chemical contamination. In general, food can become contaminated at any time through various activities, such as slaughtering or harvesting, processing, storage, distribution, transportation, and preparation [16]. Food safety risk refers to anything that poses a threat to human health and originates from the food consumed [17]. Food safety risk experiences dynamic development along with human growth due to various influences, such as natural conditions and the environment [18]. Food safety risk has two dimensions, namely the likelihood of the risk occurring and the impact generated by that risk. The character of each dimension is influenced by the conditions of the demographic group [19].

Blockchain is a form of digital innovation that is being optimised for its benefits in all fields, including the supply chain. Blockchain, known for its decentralised, transparent, and immutable system, provides a high level of accountability and traceability throughout the supply chain process, from production to distribution. By integrating blockchain, every stage of the meat supply chain can be monitored in real-time, providing greater assurance regarding product quality, safety, and halalness.

Based on the form of risk inherent in each actor's activities in the meat supply chain, the blockchain design is carried out as follows:

1. Selection of blockchain type.

In this research, the type of blockchain used is tailored to the interests of each actor. This type was chosen because the beef supply chain blockchain will be managed by various elements involved, including farmers, food processing companies, distributors, and retailers. In addition, this blockchain is closed; only certain elements (members) can enter data. This nature facilitates the data control process so as to ensure the authenticity and quality of the information inputted in the blockchain system.

2. Design of blockchain features

The blockchain features are designed in accordance with the conditions of the beef supply chain in the research location, namely East Java. In this section, the database used in the blockchain refers to food safety and halal standards. In general, the blockchain features that will be developed in this research are as follows:

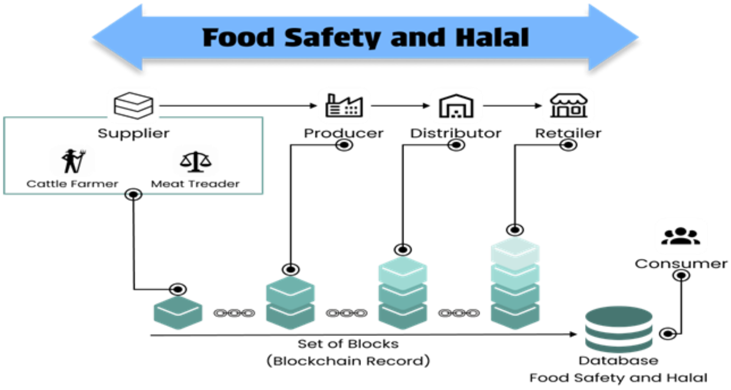

Fig. 3. Design of blockchain for meat supply chain

In this blockchain, features are designed with critical aspects of the beef supply chain in mind, including:

a. Product traceability

This traceability serves to ensure that the origin and chronological journey of beef can be traced from the farm until it is received by consumers. Features that can be used for product traceability include: cow identity, cow growth reporting, and smart contracts to validate cow data.

b. Halal certification and food safety

In this feature, the data entered is the halal certificate number issued by the authorities, namely: Halal Product Guarantee Implementing Agency (BPJPH). Only products that have a halal certificate can proceed to the next process. For food safety, the data entered in this feature is data related to cattle health conditions and laboratory testing for meat quality, including organoleptic tests, eber tests, PH tests, etc.

c. Temperature monitoring

Features for temperature monitoring on the blockchain can be designed using IoT sensors. The blockchain will record the temperature in the meat storage room. The temperature data will be stored automatically on the blockchain and cannot be manipulated. The IoT sensor is also equipped with an automatic alarm that provides information when there is an increase or decrease in temperature in the storage room.

d. Validation and assertion rights

Each party involved in the beef supply chain must have a validated identity in the blockchain system. This serves to ensure that only validated parties can use the blockchain system to enter or verify data. Access rights to the blockchain system are given to each element involved in the supply chain according to their respective roles.

e. Automatic reporting and alerting

The reporting feature of the blockchain system is used to automatically deliver information/reports to stakeholders. For example, if there is a change in temperature, the system will report to the warehouse manager automatically and in real time.

f. Smart contract

The smart contract feature serves to automate various processes related to food safety and halal. This feature will automatically validate all processes that have been guaranteed food safety and halal. For example, related to the slaughter process. The smart contract will automatically validate if the slaughter is carried out by halal butchers and uses hygienic equipment. This smart contract feature will also automatically validate payments after there is food safety and halal conformity for the transacted products.

g. Transparency

The transparency feature of the blockchain system provides an opportunity for consumers to obtain information about beef data so as to ensure food safety and halal. The transparency feature is shown through the availability of applications or QR codes. The application or QR code is placed on the beef so that it can be scanned by consumers. By scanning the QR code, consumers will obtain complete information about the beef, such as its origin, slaughterer, slaughtering process, and others, to ensure food safety and halal. The application or QR code can also be designed to display real-his status will provide confidence to consumers that the product being transacted has met the elements of food safety and halal. time status about the condition of the beef based on food safety and halal status. This status will provide confidence to consumers that the product being transacted has met the elements of food safety and halal.

3. Blockchain Architecture Design

In this architecture design, each actor in the supply chain is depicted with a node equipped with a device and server.

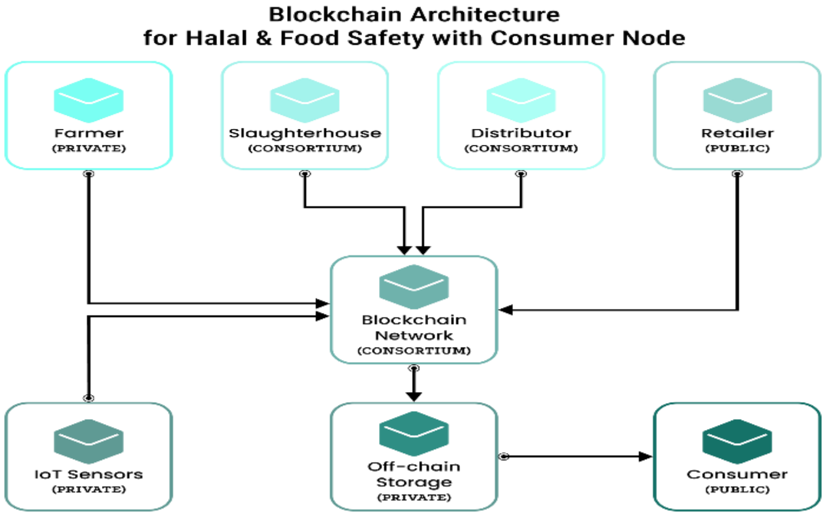

Fig. 4. Blockchain architecture design based on food safety and halal standards

The data that will be inputted by each supply chain actor based on the rankings are as follows:

Tab. 6. Blockchain data for beef supply chain based on food safety and halal standards

Supply Chains	Data
Supllier (Breeder)	1. Identity of the cow (birth/age/sex). 2. Health history 3. Halal slaughterer 4. Time and Location of slaughter 5. Method of slaughter
Manufcture	1. Halal slaughterer 2. Slaughter method 3. Time and location of slaughter 4. Food additives 5. Halal certificate number of ingredients 6. Storage room temperature 7. Product testing 8. Production and expiration time 9. Type of laboratory test
Distributor/ retail	1. Deviation room temperature 2. Vehicle cleanliness and temperature 3. Length of travel 4. Vehicle type

The data listed in Table 6 is data that needs to be inputted by each actor in the meat supply chain. After inputting, the data needs to be validated by the business actors. Once the data is validated, it is permanent and cannot be changed. The data displayed to related parties (next chain) is adjusted as needed.

5. Conclusion

This research discusses the design of blockchain for the meat supply chain with the aim of mitigating food safety and halal risks. Using the Failure Mode and Effect Analysis (FMEA) method, this research identifies potential risks at each stage of the supply chain, from farmers, producers, distributors, to retailers. Blockchain was chosen as the solution because of its transparency and accountability, which allows for real-time tracking of meat conditions from the source of the animal to the final product. The research results show that most of the risks in the meat supply chain are categorised as low risk, but there are some medium risks that need to be addressed, particularly in the slaughtering process, which is a critical point in ensuring halal status. The proposed blockchain design includes features such as product tracking, halal certification and food safety, temperature monitoring, validation, and smart contracts to automate the halal and food safety validation processes. The implementation of blockchain is expected to enhance consumer trust in the safety and halal status of products, reduce contamination risks, and strengthen accountability throughout the meat supply chain. The managerial implications of this research will increase transparency thereby increasing consumer confidence, the efficiency of risk management by business actors and strengthening compliance with certification regulatory compliance.

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