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Design of optimization strategy-based halal supply chain at a meat market in Indonesia

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Abstract

Purpose – To design an integrated halal risk mitigation strategy for the chicken meat supply chain of Indonesia. The primary focus is on identifying critical points that have the potential to threaten halal integrity from upstream to downstream in the supply chain.

Methodology – This research approach uses a combination of Failure Mode and Effects Analysis (FMEA) methods to identify and measure the level of risk at each stage of the supply chain, and Analytic Hierarchy Process (AHP) to determine the priority of mitigation strategies based on expert perspectives.

Findings – The results showed that the poultry slaughterhouse stage is the most critical point in maintaining halal products, with a priority weight of 0.51, followed by farms (0.30), and retail (0.19). The main risks identified included uncertainty in the validation of the slaughter method, non-compliance of feed and medicine with halal standards, and weak traceability of product origin in retail.

Implications – This research provides strategic contributions for policymakers, halal certification institutions, and business actors to strengthen the governance of the national halal supply chain. Applying the research results can improve the effectiveness of supervision and ensure compliance with Sharia principles as a whole.

Originality – The uniqueness of this study lies in integrating the FMEA and AHP methods in the context of the halal supply chain, which is still limited in Indonesian literature. This approach offers an evidence-based strategic framework for systematic and sustainable halal risk management.

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Introduction

The demand for halal products has increased significantly in recent decades, which is not only influenced by the growth of the global Muslim population, but also by the influence of the free trade system, increased mobility between countries, and growing consumer awareness of the importance of consumption following halal principles (Billah et al., 2020). The demand for halal products is expected to continue to increase in the future, driven by various factors such as the free market, trade between countries, and global development of the halal economy (Mabkhot, 2023). The specialization of halal products is increasing among Muslim and non-Muslim consumers, reflecting increasing consumer awareness of the importance of halal products (Farah, 2021). Muslim consumers consider halal products a must, (Alzeer et al., 2020). At the same time, non-Muslim consumers also choose halal products because of their guaranteed quality, safety, and cleanliness (Ramli et al., 2023).

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Indonesia, as one of the largest Muslim populations in the world, plays a strategic role in developing halal ecosystems, especially in the meat production sector. Around 2.18 billion of the world's 7.55 billion population in 2017 were Muslims, with Asia accounting for 69% of the total (Ayob & Saiyed, 2020). Simultaneously, the halal food market is projected to reach approximately USD 1.67 trillion by 2025, reflecting significant growth from previous years and aligning with the expanding dietary needs of Muslims, who are expected to comprise about 30% of the global population by the mid-century (Attwood et al., 2023). These data show that Indonesia has great economic potential and is responsible for maintaining the integrity of the halal supply chain, especially for highly sensitive products such as meat (Alamsyah et al., 2022).

Halal meat products in both countries come from various livestock permitted by Islam, including cows, goats, and chickens (Rahman et al., 2024). However, a significant challenge arises regarding the limited domestic meat supply, especially in Indonesia, which still experiences a deficit and relies on imports from non-Muslim countries (Khusun et al., 2022). This dependence increases the risk of violation of halal principles throughout the supply chain from the slaughtering process, packaging, transportation, and final distribution (Tseng et al., 2022). The risk of losing halal status throughout the process can reduce consumer trust and tarnish the image of the national halal industry (Khan et al., 2022).

In response to the growing challenges related to halal assurance of food products, particularly meat in Indonesia, this study aimed to identify and categorize various risks that can potentially cause the loss of halal status in meat products. Several studies have highlighted the importance of identifying critical points in the halal supply chain to maintain halal integrity (Handayani et al., 2022; Sarwar et al., 2021). However, most studies are still limited to a general context without specifically elaborating on risks in the meat sector (Fernando et al., 2023; Rahman et al., 2024).

Furthermore, existing research emphasizes aspects of certification or formal compliance but has not touched in depth on mitigative approaches based on managerial strategies and the local Indonesian context (Ardiantono et al., 2024; Tumiwa et al., 2023). Therefore, this study focuses on a comprehensive assessment of critical points along the supply chain to evaluate the probability and impact of each risk that can disrupt halal principles. The main questions asked in this study were: (1) What are the primary forms of risk that can lead to violations of halal principles in the meat supply chain? (2) What mitigation strategies can be developed to effectively minimize these risks?

Methodologically, this study uses a halal supply chain-based risk assessment approach that combines a literature analysis, expert interviews, and primary data collection to identify and classify potential risks. This study also systematically integrates risk analysis to formulate mitigation strategies compatible with international halal standards relevant to the local context.

The main contribution of this study lies in developing a conceptual and practical framework for halal risk management in the meat sector, particularly in developing countries that face structural challenges in maintaining the integrity of the halal system. The results of this study are expected to enrich scientific research in the field of halal supply chains, and provide strategic guidance for industry players and policymakers to strengthen the national halal assurance system.

Literature Review

The concept of a halal supply chain has become a significant focus in logistics and operations management studies, along with increasing awareness of Muslim and non-Muslim consumers of the importance of halal products (Rahman et al., 2023). This approach requires integration between compliance with halal standards and logistics efficiency, thus encouraging the need for an optimization strategy design in halal supply chain management (Tumiwa et al., 2023).

Several studies have emphasized the importance of identifying critical points that have the potential to cause the risk of losing halal status in the meat supply chain, such as the slaughtering process, packaging, storage, and transportation (Fathima et al., 2024). Specifically, it showed that halal integrity in the supply chain requires a systemic approach involving stakeholders from the upstream to downstream sectors, including suppliers, processors, distributors, and retailers (Ali &

Suleiman, 2018). This is also supported, emphasizing the importance of traceability and transparency in agrologist systems sensitive to quality, such as halal products (Yang et al., 2021).

In Indonesia, the country with the largest Muslim population in the world, implementing halal supply chains is not optimal (Luthviati & Jenvitchuwong, 2021). Several significant challenges that producers face regarding halal logistics principles include the absence of integration of halal certification systems in the supply chain and weak supervision of the distribution of poultry meat products (Masudin et al., 2018). In addition, the dependence on imported raw materials and complex distribution systems can increase the risk of cross-contamination and halal violations (Khan et al., 2022).

On the other hand, several studies have highlighted the role of technology and innovation in optimizing halal supply chain performance. Information technology such as digital tracking systems (halal tracking systems) can increase transparency and consumer trust (Harsanto et al., 2024). One study emphasized that technology-based optimization strategies can strengthen supply chain efficiency without sacrificing halal principles, especially in managing the distribution of meat, which has a high risk of quality and halalness degradation (Kurniawati & Cakravastia, 2023).

In addition to technological factors, regulatory and policy aspects are also important in the development of an optimal halal supply chain (Mabkhot, 2023). This highlights the need to harmonize halal standards between countries and strengthen national halal certification institutions to support the competitiveness of halal products in the global market (Khan et al., 2019). However, the limitations in adopting the policy in Indonesia are still obstacles to realizing a resilient and standardized halal supply chain (Ardiantono et al., 2024).

From a methodological perspective, previous studies have generally used a descriptive qualitative approach to describe problems in the halal supply chain. However, optimization-based approaches and mathematical modeling have been developed in the last decade to provide more applicable and systematic solutions. Optimization models such as Linear Programming (LP), Analytic Hierarchy Process (AHP), and Fuzzy Inference System (FIS) are used to formulate strategies that are not only halal according to Sharia, but also economically efficient and sustainable.

This literature review shows that although the global literature has provided a strong foundation for the importance of halal and logistics integration, there is still a gap in implementing the concept in the Indonesian meat sector. Therefore, this study aims to fill this gap by proposing a halal supply chain-based optimization strategy design that is relevant to local conditions but still refers to international best practices. Thus, the scientific contribution of this study not only enriches the halal logistics literature, but also provides practical implications for industry players, regulators, and policymakers in the halal food sector.

Regarding the approach used, it should be emphasized that this study does not develop formal hypotheses, as its primary objective is to formulate an optimization strategy based on risk analysis and prioritization. An exploratory and descriptive approach combined with quantitative methods such as FMEA and AHP is more appropriate for designing operational strategies based on multi-criteria decisions. Therefore, the elimination of hypotheses is a deliberate methodological decision that has been adapted to the characteristics of the research objectives and approach.

Research Methods

This study employed a quantitative approach with a descriptive design because it provides an objective and comprehensive picture of the actual conditions of the halal supply chain (HSC), particularly in the context of the Indonesian meat industry. This design is considered relevant to the primary objective of this study, which is to systematically identify, evaluate, and prioritize risks at each stage of the halal supply chain based on measurable data. A quantitative-descriptive approach is also widely recommended in halal logistics studies because it allows the formulation of risk-mitigation models based on empirical conditions and reliable numerical analysis (Kristanto & Kurniawati, 2023).

Primary data were obtained through a survey distributed to halal meat supply chain business actors operating in West Java and East Java provinces, two regions known geographically, demographically, and economically as national centers of meat production, processing, and

distribution. A purposive sampling technique was used to select respondents with the following inclusion criteria: (1) active business actors in the halal meat industry with at least three years of experience; (2) direct involvement in operational activities at one or more stages of the HSC; and (3) practical understanding of halal principles and procedures in the supply chain.

The demographic profile of the respondents shows that 68% were male and 32% were female, with the majority aged between 30 and 50 years. Fifty-four percent of the respondents had at least a diploma, while 46% were high school graduates with vocational technical training. Based on the type of involvement, 20% of respondents were livestock farmers, 25% were slaughterers, 30% were processing, 15% were distributors, and 10% were at the retail level. The total number of valid respondents analyzed in this study was 100. The selection of this research location not only considered the comprehensiveness of the halal meat supply chain structure, but also the high consumer awareness of halal products and the dynamics of the regional market, which is very active in consuming halal-certified animal protein.

The data collection instrument used was a structured questionnaire designed based on a review of the current literature and adapted to the needs of the analysis in the HSC context. The questionnaire was divided into three main sections: (1) respondent characteristics, (2) description of the HSC operational practices implemented, and (3) assessment of potential risks at each stage of the process. In this study, the main stages of the halal meat supply chain were classified into five phases: (1) farming, (2) slaughtering, (3) processing, (4) distribution, and (5) retail. Each phase was analyzed to identify potential risks that could lead to the loss of halal status, including cross-contamination, non-compliance with Islamic slaughter procedures, and weaknesses in the product traceability system.

To ensure the quality and feasibility of the research instrument, a pilot test was conducted with 10 respondents outside the main sample. The test results showed that all items in the questionnaire had a Cronbach's alpha value of > 0.7, indicating excellent internal reliability(Hair et al., 2022). Construct validity was tested using exploratory factor analysis (EFA), which demonstrated significant factor loadings (> 0.5) and consistency between the relevant constructs. The instrument design and risk identification process are based on a holistic system-based halal risk management approach, emphasizing the principles of integration and oversight across critical points in the halal logistics system(Khan et al., 2021).

Data analysis used two main approaches: Failure Mode and Effects Analysis (FMEA) and Analytic Hierarchy Process (AHP). FMEA was used to detect potential failures in the HSC system, focusing on the production and distribution of chicken meat given the high sensitivity of halal certification for this commodity. Each potential failure is assessed based on three parameters: severity (impact), occurrence (frequency of occurrence), and detection (ability to detect failure), which are then multiplied to produce a Risk Priority Number (RPN). The RPN prioritizes risks that require immediate action (Altubaishe & Desai, 2023; Boral et al., 2020).

After all potential risks were identified and prioritized based on their RPN values, the AHP method was applied to formulate the optimal mitigation action alternatives. The AHP procedure involves constructing a pairwise comparison matrix between risk criteria and alternative solutions and then calculating their priority weights hierarchically (Fahadha et al., 2019). This method has proven effective in supporting strategic decision making based on logical and consistent preferences (Lahane & Kant, 2021).

All data processing and analysis were conducted using IBM SPSS Statistics version 26 software for descriptive analysis and reliability testing and Expert Choice v11.5, as a tool for AHP calculations and analysis. The analysis results are presented in tables, graphs, and visual schematics to facilitate straightforward interpretation by the readers and relevant stakeholders.

Results and Discussion

Animal welfare is a critical point in the halal beef supply chain at the feedlot (fattening) stage. According to the Law of the Republic of Indonesia Number 18 of 2009 concerning Animal Husbandry and Animal Health, animal welfare is defined as all matters relating to animals' physical and mental conditions following their natural behavior, which must be implemented to protect

animals from improper human treatment. In the context of the halal certification standards established by the Indonesian Ulema Council (LPPOM MUI), the livestock rearing stage does not directly result in noncompliance with halal principles, formally beginning with the slaughter process. However, the holistic concept of halal emphasizes the principle of halalan thayyiban (halal-based), namely that the halalness of the product must be maintained from upstream to downstream (farm to fork), including the livestock cultivation process, which is considered a critical point in the halal product assurance system (Rejeb et al., 2021).

Through in-depth interviews conducted by researchers with LPPOM MUI representatives in 2025, several risks related to animal welfare during the cultivation stage were identified. These risks include (i) difficulty obtaining information about livestock husbandry processes from farmers, (ii) limited availability of halal-certified supplements and medicines, (iii) challenges in ensuring a minimum distance of 5 km from pig farms, and (iv) difficulties in scheduling feed, drinking water, and regular livestock health checks. Interviews also indicated that slaughterhouses (RPH) could still obtain halal certification in some regions, such as Bali, even if they did not meet the minimum distance from pig farms. As long as slaughterhouse managers can systematically demonstrate no risk of cross-contamination from the surrounding environment, this is possible.

As explained in the interviews, regulations regarding the minimum distance between slaughterhouses and pig farms were explicitly regulated, but no longer strictly enforced over time. This leniency is provided for contextual considerations, particularly in regions with a high geographical density of nonhalal farms. Therefore, some risks at the cultivation stage are not considered entirely crucial if the mitigation of potential contamination can be demonstrated transparently and audited. This finding reinforces the view that implementing the halal supply chain requires an approach that is adaptive to local conditions but remains based on the principle of halal integrity as a whole (Alamsyah et al., 2022). Animal welfare risks in the halal context are shown in Table 1.

Table 1. The halal risks feedlots risk priority number (RPN) in Indonesia

Codes	The halal risks in feedlots	RPN
HRF1	Difficulty in obtaining information on the calf production process.	72
HRF2	Challenges in obtaining protein supplements for animal feed that have a halal logo.	90
HRF3	Difficulty in obtaining animal drug supplements that are guaranteed halal.	90
HRF4	There is no clear schedule for providing drinking water for cows.	14
HRF5	There is no set schedule for feeding cows.	14
HRF6	There is no routine health check schedule for cows.	10

Source: Primary data processed

Table 1 identifies six types of halal risks found in the cattle fattening process in Indonesia, each accompanied by a Risk Priority Number (RPN), indicating the level of urgency of its handling. The highest RPN was recorded for two risks, HRF2 (challenges in obtaining animal feed protein supplements that have a halal logo) and HRF3 (difficulty in obtaining animal drug supplements that are guaranteed to be halal), both of which received an RPN score of 90. This value indicates that feed and drug inputs are critical in the halal supply chain, especially in the fattening process, which requires priority intervention in the halal assurance system.

Meanwhile, HRF1, which reflects the difficulty in obtaining information on the calf production process, is ranked next, with an RPN of 72, indicating a gap in traceability, which is also important in halal certification. The other three risks, namely HRF4, HRF5, and HRF6, are related to the absence of a clear schedule regarding the provision of drinking water, feed, and routine health checks for cattle. Although the RPN value is relatively low (between 10 and 14), it still shows that the managerial and procedural aspects need strengthening to support the comprehensive implementation of halal principles.

Table 2. The halal risks of slaughterhouses in Indonesia

Critical point	Codes	The halal risks in slaughterhouses	RPN
Stunning	HRS1	Difficult to validate that stunning does not cause an animal's death.	34
	HRS2	Difficult to validate that stunning causes animal pain.	140
	HRS3	Difficult to avoid, a stunning human error causes a lack of the halal requirement of cattle.	54
Knife	HRS4	There is no clear schedule for providing drinking water for cows.	27
Slaughter	HRS5	Difficult to meet a halal requirement that a slaughterer should own a halal certificate and an identity card from the Islamic Institution.	14
	HRS6	Difficult to meet the halal requirement that a slaughter should own a regular medical record.	54
	HRS7	Difficult to avoid a slaughtering human error that causes a slice of non-halal meat.	30
Invocation	HRS8	Difficult to form a halal awareness that saying Basmallah is a halal requirement	21

Source: Primary data processed

Table 2 groups halal risks in slaughterhouses based on their critical points, namely stunning, knife, slaughtering, and invocation (prayer). The highest risk was identified in HRS2, namely the difficulty in verifying that the stunning process does not cause pain to the animal, with an RPN score of 140. This value indicates that stunning is the main vulnerable point for violations of animal welfare principles in halal. It has the potential to cause non-compliance with sharia if not handled with strict procedures that can be proven scientifically and follow sharia.

Other significant risks are found in HRS3 (human error in the stunning process that causes halal requirements not to be met) with an RPN of 54 and HRS6 (difficulty in meeting routine medical requirements for slaughterers) with the same RPN. HRS7 (human error during slaughter, which causes parts of meat to be non-halal) is also a concern, with an RPN of 30. This indicates that in addition to technical problems with the equipment, the competence and consistency of the workforce in implementing halal standards are also significant challenges.

Other risks, such as HRS1, HRS4, HRS5, and HRS8, reflect administrative challenges and spiritual awareness in the halal slaughtering process, with a relatively lower RPN (ranging from 14 to 34). However, aspects such as validation of the slaughterer's identity and awareness in saying Basmallah remain important elements that must be guaranteed for sustainability in slaughterhouse industry practice.

Table 3. The halal risks of retail in Indonesia

Codes	The halal risks in slaughterhouses	RPN
HRR1	Difficult to form halal awareness for management and employees related to transportation and storage.	7
HRR2	Difficult to provide a special storage place on the market for halal meat before being distributed to outlets.	45
HRR3	Difficult to separate the halal meat outlet in the market from the pig outlet.	5
HRR4	Difficult to distinguish the origin of halal meat sent from slaughterhouses from meat shipped from other places.	72

Source: Primary data processed

Table 3 maps four types of halal risks in Indonesia's halal meat distribution and retail chain. The highest risk is in HRR4, which distinguishes the origin of halal meat sent from halal slaughterhouses from meat from other places, with an RPN of 72. It shows that the traceability system and supervision of halal meat distribution are still not running optimally, and have the potential to cause mixing between halal and non-halal meat.

Another significant risk that is also quite significant is HRR2 (difficulty in providing special storage space in the market for halal meat before it is distributed to outlets), with an RPN of 45. This risk shows the weakness of the halal logistics infrastructure at the traditional market and retail levels, which can cause cross-contamination.

Meanwhile, HRR1 and HRR3 are related to management and team member halal awareness related to transportation and storage, and the difficulty separating halal meat outlets from pork outlets has a low RPN, at 7 and 5, respectively. However, these low values do not necessarily indicate the unimportance of these risks but rather reflect a lower relative urgency compared to tracking and storage risks. Therefore, an educational approach and strengthening of regulations are still needed to sustainably build halal culture in the retail sector.

Based on the results of risk identification at each stage of the halal chicken meat supply chain in Indonesia, a priority analysis was conducted using the Analytical Hierarchy Process (AHP) method to design an appropriate and effective mitigation strategy. The AHP method was chosen because it accommodates multi-criteria decisions systematically and objectively, considering various complex factors and alternatives (Saaty, 1990; Stofkova et al., 2022). The analysis is performed by compiling a hierarchical structure consisting of primary objectives, criteria, and alternative strategies adjusted to the risk characteristics that emerge from previous FMEA data.

At the first level of the hierarchy, the main objective was to optimize the halal chicken meat supply chain in Indonesia". The second level consists of three main criteria that reflect critical points in the supply chain: feedlots, slaughterhouses, and retail risks. Each criterion is then analyzed based on the highest Risk Priority Number (RPN) value to highlight the most urgent risks to be addressed. In feedlots, the highest risks were found in HRF2 and HRF3 (RPN = 90), which are related to difficulties in obtaining feed supplements and medicines with halal assurance. The highest risk in slaughterhouses is HRS2 (RPN = 140), which is the inability to validate that the stunning method does not cause pain to animals and has the potential to violate the basic principles of animal welfare in Islamic law. Meanwhile, in retail, HRR4 (RPN = 72) shows a high challenge in distinguishing the origin of halal meat from slaughterhouses and meat from other sources, which can obscure the halal validity of the products received by consumers.

Based on the results of the assessment and weighting using Expert Choice, priority weights for each criterion were obtained: slaughterhouses (0.51), feedlots (0.30), and retail (0.19). This shows that the slaughterhouse stage is the most significant critical point, requiring greater strategic attention in fulfilling halal standards. At this stage, the recommended strategic approach includes improving the training of animal slaughterers following the standards of the Indonesian Ulema Council (MUI), strict supervision of the use of the stunning method, and providing facilities and slaughter procedures that comply with Islamic law (Suryawan et al., 2022). The importance of technical and religious validation during slaughter was emphasized to ensure integrity (Abdallah et al., 2021).

At the upstream level, particularly in the feedlot sector, recommended priority strategies include developing a halal certification system for animal feed and pharmaceuticals as well as strengthening collaboration with local producers to increase the availability of halal-certified livestock additives (Bux et al., 2022). However, implementing this certification system is challenging because of several structural and technical challenges. Key challenges include limited capacity in feed raw material testing laboratories, low halal literacy among small- and medium-sized feed producers, and the absence of national technical standards that specifically regulate the halal certification of additional components such as enzymes, probiotics, and vitamins used in feed (Alzeer et al., 2020). In this context, strategic collaboration with local producers serves to meet supply needs and as a means of knowledge transfer and harmonizing the halal quality system. This approach aligns with the principles of upstream risk management in the halal supply chain, where failures at early stages have a systemic impact on halal integrity downstream.

Meanwhile, the primary proposed strategy at the retail level involves implementing a blockchain-based digital tracking system and restructuring the market layout to physically separate halal and non-halal outlets (Tan et al., 2022). Blockchain technology not only provides transparency regarding product origins, but also offers unique advantages in the form of immutability (the

inability of data to be unilaterally altered) and decentralized data security, which are crucial in ensuring the integrity of halal supply chain information (Susanty et al., 2024). Every transaction and product movement is permanently recorded and cannot be manipulated, thereby strengthening consumer confidence in product halal claims. Furthermore, the physical segregation of halal and non-halal products in the market is crucial for preventing intentional and unintentional cross-contamination. This arrangement reflects the principle of a halal assurance system based on preventive control, rather than simply reacting to incidents of violation. Thus, retail strategies are not only operational, but also reflect ethical and symbolic commitments to fulfilling the Sharia values expected by Muslim consumers.

In general, the strategic design developed using the Analytical Hierarchy Process (AHP) approach in this study not only reflects real-world conditions but also provides a priority framework that can be utilized by policymakers, business actors, and halal certification bodies in formulating more targeted policies and interventions (Boral et al., 2020). The advantage of the AHP approach in this study lies in its ability to integrate quantitative data obtained through the Failure Mode and Effect Analysis (FMEA) method with qualitative considerations from experts and stakeholders, resulting in more comprehensive and adaptive strategic decisions to address actual challenges at various critical points in the halal supply chain.

In the context of FMEA, three main dimensions are used to evaluate risk: (1) the Probability of Occurrence, which is the likelihood of a risk occurring at each stage of the process; (2) severity, which measures the risk's impact on the product's halal integrity; and (3) Detection Capability, which describes the system's likelihood of detecting a risk before it has an impact. Each dimension was scored on a scale of 1–10, and the final risk score was calculated using the formula: Risk Priority Number (RPN) = occurrence × severity × detection. The highest RPN value indicates that risk requires priority management (Altubaishe & Desai, 2023). The obtained RPN values were then converted into a pairwise comparison matrix within the AHP framework to identify the priority weights of the most effective mitigation strategies at each stage of the supply chain. This conversion process follows the approach of integrating the FMEA into the AHP-based strategic decision-making hierarchy.

The results indicate that the most urgent strategic interventions are at the slaughter stage, indicating the need to formulate stricter technical policies by halal certification bodies and the government. Increasing halal awareness at the feedlot stage is also crucial and needs to be prioritized by providing incentives for animal feed and pharmaceutical producers to obtain halal certification. Meanwhile, on the downstream side, using digital technology for halal tracking can strengthen consumer trust, even though the level of urgency is relatively low compared to the previous two stages.

Conclusion

This research explicitly answers the primary question posed at the outset: What are the most impactful critical risks in Indonesia's halal chicken supply chain, and what mitigation strategies are most appropriate for prioritizing them? Through a combination of FMEA analysis and the Analytical Hierarchy Process (AHP) method, this study identified critical points at three key supply chain stages—farming, slaughterhouses, and retail—and prioritized relevant mitigation strategies based on the highest risk weight.

The AHP results indicate that the slaughtering process has the highest risk weight (0.51), followed by farming (0.30), and retail (0.19). Therefore, it can be concluded that the slaughtering stage is the most urgent critical point that requires strategic intervention to maintain the overall halal integrity. Key strategies at this stage include improving the training of certified slaughterers following the Indonesian Ulema Council (MUI) standards, strict supervision of stunning methods, and provision of slaughtering facilities that comply with Islamic law. This strategy is not only technically important, but also has a crucial theological dimension, as it emphasizes that the validation of halal slaughter is a key determinant of Muslim consumer trust.

At the upstream stage, namely livestock farming, recommended mitigation strategies include developing a halal certification system for animal feed and medicines and strengthening

collaboration with local producers to ensure the availability of halal-certified additives. This approach is crucial for strengthening the supply chain from the outset, given that potential risks at this stage can have systemic consequences for the final product's halal status. Downstream, recommended strategies include implementing a blockchain-based digital tracking system to ensure the transparency of product origins and restructuring markets to physically separate halal and non-halal outlets. Although the risks in the retail stage are numerically lower, these strategies have significant value in building consumer trust and preventing cross-contamination.

Practically, the results of this study have significant implications for formulating national policies in the halal logistics sector, particularly for designing more targeted and risk-based technical and regulatory interventions. These findings can also serve as strategic references for industry players, halal certification bodies, and local governments in developing supply chain systems that are efficient and compliant with globally recognized Sharia values.

However, this study had several limitations. First, the geographic scope of the study is limited to only two provinces in Indonesia: West Java and East Java. Therefore, this does not represent the overall dynamics of the national halal supply chain. Second, the FMEA and AHP data are cross-sectoral and do not accommodate segmentation based on business scale (MSMEs vs. large corporations). Third, because this study used a quantitative approach, the qualitative perspectives of consumers and business actors have not been explored in depth, particularly regarding risk perceptions and halal practices.

Based on these findings and limitations, future studies are recommended to: (1) expand the research area to include other regions in Indonesia with different halal supply chain characteristics, such as Sumatra, Kalimantan, and Sulawesi; (2) develop a mixed-methods approach that combines quantitative and qualitative analyses to gain a more holistic understanding; and (3) integrate a dynamic simulation model to project the long-term impact of various proposed mitigation strategies on the efficiency and integrity of the national halal supply chain.

Thus, this research not only answers operational issues in the halal supply chain, but also opens up opportunities for theoretical and practical contributions that can sustainably strengthen the halal assurance system in Indonesia and the ASEAN region, which has a rapidly growing Muslim market.

Author contributions

Conceptualization: Rizqa Ula Fahadha
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Investigation: Rizqa Ula Fahadha
Methodology: Rizqa Ula Fahadha
Project administration: Rizqa Ula Fahadha
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Validation: Sutarto
Visualization: Rizqa Ula Fahadha
Writing – original draft: Rizqa Ula Fahadha
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