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Risk Assessment and Mitigation of Halal Meat Supply Chain Systems Using Best-Worst Method and PROMETHEE

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ABSTRACT

The halal meat supply chain is exposed to a series of identifiable and significant risks, including incomplete information about the origin and health of livestock, non-compliance with halal slaughtering procedures, and inadequate post-slaughter inspections. These risks pose serious threats to the integrity, traceability, and consumer trust in halal products. However, prior studies often address risk assessment and mitigation in isolation, lacking an integrated framework that links risk prioritisation with targeted mitigation strategies. This study proposes a comprehensive model for assessing and mitigating risks in the halal meat supply chain using the Best-Worst Method (BWM) and the Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE). Risks were identified through a literature analysis and expert validation, and then prioritised using the BWM. PROMETHEE was applied to rank alternative mitigation strategies based on these prioritised risks. The findings highlight that the most critical risks include incomplete information about delivered cattle (S4), slaughterers not following standard operating procedures (PP6), and cattle that do not meet health standards (S2). The top-ranked mitigation strategies include: establishing formal agreements detailing halal standards (M16), routine monitoring of slaughtering processes (M12), staff education on SOP compliance (M6), and enforcement of disciplinary measures (M10). Academically, this study introduces a novel BWM–PROMETHEE integration within halal supply chain risk management, an area with limited existing literature. Practically, it offers a structured decision-making tool to enhance halal integrity through risk-informed management interventions at the operational level.

1. Introduction

Halal refers to what is permissible according to Islamic law, as outlined in the Qur'an [1]. In the food industry, particularly in Indonesia, where the majority of the population is Muslim, the halal meat supply chain plays a vital role [2]. Even non-Muslim consumers appreciate halal-labelled products due to their perceived assurance of quality and safety

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[3]. However, maintaining the halal status of meat from upstream to downstream presents significant challenges. Each stage in the supply chain, from selecting animals that comply with Islamic requirements to distributing the meat to end consumers, must be strictly monitored to ensure compliance with halal principles [4]. In addition, all equipment, containers, and surfaces that come into contact with meat and offal must be made from food-grade materials that are non-toxic, corrosion-resistant (such as stainless steel or galvanised metals), and easy to clean, disinfect, and maintain [5]. Risks such as cross-contamination, lack of halal certification, or violations at any stage of the process can compromise the halal integrity of the product. Non-compliance in the slaughtering procedure, improper animal selection, and discrepancies during distribution also pose serious threats. Therefore, comprehensive risk assessment and the implementation of effective mitigation strategies are essential to ensure the halal status of meat products, meet consumer expectations, and uphold halal integrity.

In recognition of its status as a Muslim majority country, Indonesia enacted the Halal Product Assurance (JPH) Law (Law No. 33/2014), which provides a regulatory framework to ensure the halal compliance of products consumed and used, under the supervision of the Halal Product Guarantee Agency (BPJPH) [6]. Despite these institutional efforts, compliance remains inconsistent at the operational level, especially in small-scale slaughterhouses (RPH-R). Bangkalan, located in East Java, presents a representative case where halal compliance challenges persist due to limited supervision, infrastructure, and training of slaughterhouse staff. The Ruminant Slaughterhouse (RPH-R) in Bangkalan operates under regional government oversight but lacks a formalised risk management framework to ensure continuous halal compliance. Previous audits and internal evaluations have highlighted recurring issues, such as undocumented livestock origins, procedural errors in slaughter, and hygiene problems, all of which can compromise the halal status. Thus, this study situates itself in a real-world institutional setting that reflects the common challenges faced by local halal meat supply chains in Indonesia.

Numerous studies have examined risk assessment within the halal meat supply chain using various methodologies. Rishelin and Ardi [7] employed a DEMATEL-based ANP to model interdependencies among risk factors; however, their approach did not include mitigation strategies. Azli, et al. [8] used a qualitative assessment scale, which lacks robustness for prioritisation. Wahyuni, et al. [9] and Kusuma [10] used SCOR-HOR and HOR methods, respectively, but did not incorporate multi-criteria decision-making (MCDM) techniques to evaluate mitigation strategies. Wahyuni, et al. [11] adopted Bayesian Networks to quantify uncertainty, although the model complexity makes it less suitable for practical implementation. Ramli, et al. [12], [13] applied Halal Critical Point (HCP) and FMEA approaches, yet these are limited to risk identification and ranking without integrating strategy selection. Meanwhile, Mansur, et al. [14] explored HOR for mitigation, but the decision-support structure remains limited. More recent studies such as those by Khan, et al. [15] and Sumarliah, et al. [16] applied fuzzy BWM to prioritise risks. However, these works did not propose actionable mitigation alternatives. Similarly, Khan, et al. [17] used fuzzy AHP, but focused only on risk assessment without connecting it to practical interventions. Overall, these studies have contributed valuable insights, but most treat risk assessment and mitigation as separate tasks. There remains a gap in integrating risk prioritization with the selection of mitigation strategies within a structured MCDM framework. This study addresses that gap by integrating BWM for risk assessment and PROMETHEE for prioritizing mitigation strategies, thus offering a holistic and actionable model for managing risks in halal meat supply chains.

Given the critical need for integrated risk assessment and mitigation in the halal meat supply chain, this study adopts a structured decision-making approach using the Best-

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Worst Method (BWM) and the Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE). These methods are chosen to address the limitations of previous studies that typically treated risk assessment and mitigation as separate processes. BWM was selected due to its efficiency in eliciting expert preferences with fewer comparisons compared to traditional methods such as AHP and ANP [18]. It reduces subjectivity and produces consistent weightings by focusing on the best and worst criteria [19]. PROMETHEE complements BWM by offering a robust and interpretable mechanism for prioritising mitigation strategies across multiple criteria, with superior stability and insensitivity to normalisation issues compared to other MCDM methods, such as TOPSIS, VIKOR, and ELECTRE [20] [21]. This study contributes both theoretically and practically. From an academic perspective, it introduces the first integration of BWM–PROMETHEE specifically for operational halal meat supply chains. While these methods have been employed in other sectors, such as location selection [22], supplier evaluation [23-25], and school performance ranking [26], they have not been jointly applied in halal auditing contexts. Practically, the framework supports decision-makers in slaughterhouses and halal authorities in prioritising limited resources, developing targeted training, and enforcing SOPs based on the quantifiable significance of risk. By offering a replicable and transparent decision-support model, this study enhances institutional halal compliance. It addresses persistent gaps in halal food governance.

2. Methods

After understanding the various methods employed in previous studies, this study proposes an integrated framework for assessing and mitigating halal supply chain risks. This framework comprises four sequential stages that ensure both analytical rigour and practical relevance. The first stage involves identifying risks in the halal meat supply chain through a literature review, site observations, and expert consultation. The second stage involves risk assessment using the BWM, which enables the robust and consistent weighting of each identified risk. In the third stage, risk prioritisation is carried out using a Pareto chart, which helps identify the most critical risks that require immediate action. The fourth stage involves assessing risk mitigation alternatives using the PROMETHEE method, which ranks strategies based on how effectively they address prioritised risks. The complete process is visualised in Figure 1, which illustrates the logical and methodological flow of this research from risk identification to strategic mitigation evaluation.

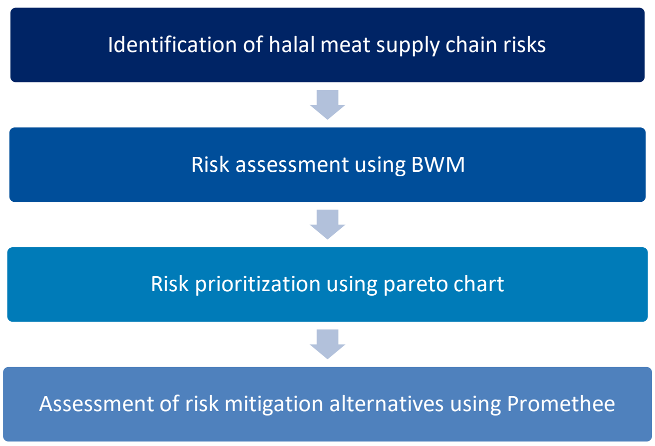

Figure 1 Research Framework

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2.1 Best-Worst Method

This study employs the linear BWM approach to conduct risk assessment in the halal meat supply chain. The BWM, developed by Rezaei [27], is recognised for its efficiency in determining criterion weights with fewer pairwise comparisons compared to other methods such as the AHP. The first step in applying BWM involves identifying all relevant risks in the halal meat supply chain, denoted as the set $\{C_1, C_2, \ldots, C_n\}$. These risks were identified through a combination of literature reviews, direct on-site observations, and in-depth discussions in the form of a Focus Group Discussion (FGD) involving three key stakeholders: the head of RPH-R and two halal supervisors. These individuals were selected based on their direct responsibility and operational knowledge of halal practices, slaughtering procedures, and quality control at RPH-R. Although limited in number, the selection represents the complete internal decision-making authority within the slaughterhouse, aligning with the BWM recommendation for small but expert-driven elicitation. To ensure the robustness of pairwise comparisons, a consensus approach was adopted during the FGD. Rather than collecting independent inputs, experts discussed and agreed upon each comparison ratio collaboratively. This facilitated the construction of a single, unified comparison matrix that reflects shared institutional judgment rather than individual bias, which is particularly appropriate given the operational and policy-oriented scope of this research.

The next step is to determine two risks, namely the best risk (most important), denoted as B. The worst risk (least important), denoted as W. This selection is made based on expert opinion through focused discussions. After that, respondents are asked to provide preference ratings of the best risk relative to other risks using a scale of 1 to 9 as shown in Table 1. This assessment produces a comparison vector of the best risk relative to all other risks, denoted as $A_B = (a_{B1}, a_{B2,\ldots\ldots,} a_{Bn})$, which indicates how much more important risk B is than risk C_j. Similarly, experts provided preference ratings of all other risks relative to the worst risk, resulting in the vector $A_W = (a_{1,} a_{2W,\ldots,} a_{nW})^T$, where a_{jw} indicates how much more important risk C_j is than risk W.

After the two preference vectors are obtained, the next step is to calculate the optimal weights for each risk, denoted as $w_1^*, w_2^*, w_3^*, \ldots w_n^*$. The optimal weights are calculated by constructing a linear programming model that minimises the maximum deviation between the actual weight ratios and the preference values provided by the respondents. The consistency index denotes this deviation $\tilde{\xi}$, which represents the level of inconsistency in the pairwise comparisons. The model is formulated in Equation (1). The use of LINGO ensured the reliability and accuracy of the computed weights. To ensure the reliability of expert judgments, the resulting $\tilde{\xi}$ value was checked for all comparison matrices. According to Rezaei [27], a lower $\tilde{\xi}$ value (closer to 0) indicates higher consistency. In this study, all $\tilde{\xi}$ values obtained were below 0.1, which is considered acceptable and demonstrates that the judgments made during the FGD were consistent and credible, in line with thresholds suggested by Rezaei [27]. The linear programming formulation for calculating optimal weights in the BWM was implemented using LINGO 18.0 software. LINGO was chosen due to its capability to efficiently solve optimisation problems and generate consistency ratio (ξ values) as part of the solution output.

$$\min \tilde{\xi}^L \; s.t. \begin{cases} |W_B - a_{Bj} W_j| \\ |W_j - a_{jw} W_w| \end{cases} \leq \tilde{\xi}^L \, for \; all \; j;$$
$$\sum_j W_j = 1 \tag{1}$$
$$W_j \geq 0, for \; all \; j$$

where:

$\tilde{\xi}^L$	: Inconsistency.
W_B	: Best risk weight.
W_j	: Weight of risk j.
W_w	: Worst risk weight.
a_{Bj}	: Comparison value between the best risk and risk j.
a_{jw}	: Comparison value between risk j and the worst risk.

To enhance the transparency and reproducibility of the method, the implementation of BWM in this study followed a structured computational process. After the best and worst risks were identified, experts were asked to complete structured pairwise comparisons using standardised BWM questionnaires. The resulting comparison vectors were encoded into a linear programming model and solved using LINGO 18.0, which efficiently computed the optimal weights and the consistency ratio ($\tilde{\xi}$). Each risk weight and $\tilde{\xi}$ value output was verified against thresholds suggested by Rezaei [27], and values below 0.1 were accepted as consistent. Additionally, to aid replication, the complete decision matrix and solution structure have been made available upon request, ensuring methodological clarity for future studies.

Table 1 Pairwise comparison scale BWM

Intensity of Importance	Verbal Meaning for Risk Comparison
1	Equally important
2	Equal to slightly more important
3	Slightly more important
4	Slightly to moderately more important
5	Moderately more important
6	Moderately to significantly more important
7	Significantly more important
8	Significantly to extremely more important
9	Extremely more important

2.2 PROMETHEE

The PROMETHEE was applied in this study to determine the most effective risk mitigation strategy in the halal meat supply chain system. PROMETHEE was chosen for its ability to systematically, consistently, and transparently address multi-criteria decision-making issues. This method prioritises alternatives based on pre-calculated risk weights and preferences using the BWM. The analytical framework is designed to generate the most effective mitigation strategies for addressing the identified key risks.

The initial stage in applying the PROMETHEE method is to identify relevant risk mitigation strategy alternatives. The identification process was conducted through a review of current literature and in-depth discussions in the form of Focus Group Discussions (FGDs) with three key parties involved in the operations of RPH-R Bangkalan, namely the RPH-R Head and two Halal Supervisors. The selected alternatives are based on literature studies and existing risks, making them highly relevant to the

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risks faced. Following this, risk prioritization is established based on the results of the Pareto chart from the previous analysis stage. These risks serve as the basis for evaluating the performance of each mitigation alternative.

The performance values of each alternative with respect to each prioritised risk were generated through expert judgment using a structured Likert scale. During the FGD, the same three experts who participated in the BWM stage were asked to evaluate the effectiveness of each mitigation strategy (alternative) in addressing each specific risk, using a 5-point Likert scale ranging from 1 (very low effectiveness) to 5 (very high effectiveness). The values were agreed upon through a consensus process, ensuring consistency and institutional relevance. These aggregated Likert-based scores formed the input performance matrix for PROMETHEE, which was then used to calculate preference indices and outranking flows. The next step is to develop an evaluation matrix, which lists the preference values of each mitigation alternative for each identified risk. To evaluate how much better one alternative is compared to another in addressing a specific risk, the deviation between alternative pairs is calculated using Equation (2). For the PROMETHEE analysis, Microsoft Excel was used to construct the evaluation matrix and implement the PROMETHEE I and II algorithms. The calculations of preference functions, outranking flows, and ranking of mitigation strategies were conducted using Excel functions and matrix operations, enabling transparency and easy reproducibility of the decision-making process.

$$d_j(a,b) = C_j(a) - C_j(b) \quad (2)$$

where:

$d_j(a,b)$: Deviation between alternatives a and b in risk j.
$C_j(a)$: Risk value j for alternative a.
$C_j(b)$: Risk value j for alternative b.

The calculated deviation is then converted into a preference value using the Usual preference function. This function was chosen because it is considered most suitable for use in conditions involving multiple risks [28], as shown in Equation (3).

$$P_j(a,b) = \begin{cases} 0, if \ d_j(a,b) \leq 0 \\ 1, if \ d_j(a,b) > 0 \end{cases} \quad (3)$$

where:

$P_j(a,b)$: Preference value for risk j between alternatives a and b.
$d_j(a,b)$: Deviation between alternatives a and b for risk j.

Once all preference values have been obtained, calculate the aggregate preference index for each pair of alternatives using Equation (4).

$$\pi(a,b) = \sum_{j=1}^{n} P_j\,(a,b) W_j \quad (4)$$

where:

$\pi(a,b)$: Aggregate preference index for alternative a over b.
$P_j\ (a,b)$: Preference value for risk j between alternatives a and b.
W_j : Weight of risk j.
n : Number of alternatives.

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The next step is to calculate the positive and negative outranking flows. The positive outranking flow ($\emptyset^{+}(a)$) measures the extent to which alternative a is better than other alternatives, while the negative flow ($\emptyset^{-}(a)$) shows the extent to which other alternatives outperform alternative a. Based on Equations (5) and (6).

$$\emptyset^{+}(a) = \frac{1}{m-1}\sum_{b=1}^{n}\pi(a,b) \quad (5)$$

$$\emptyset^{-}(a) = \frac{1}{m-1}\sum_{b=1}^{n}\pi(b,a) \quad (6)$$

where:
$\emptyset^{+}(a)$: Positive outranking flow for alternative a.
m : Number of alternatives.
$\pi(a,b)$: Aggregate preference index for alternative a over b.
$\pi(b,a)$: Aggregate preference index for alternative b over a.

For the PROMETHEE implementation, a structured Likert-scale-based evaluation matrix was created during the expert FGD session. This matrix captured the perceived effectiveness of each mitigation alternative against each risk. These values were then processed using Microsoft Excel, where a custom PROMETHEE worksheet was designed to compute pairwise deviations, preference values (using the Usual function), aggregate preference indices (π), and finally, the positive and negative outranking flows ($\emptyset^{+}$ and $\emptyset^{-}$). All calculations adhered to standard PROMETHEE I and II formulations, ensuring that rankings could be reproduced with complete transparency.

3. Results and Discussion

Based on the methodological framework described, the following section presents the results of the risk analysis and mitigation strategies derived from the application of the BWM and PROMETHEE methods.

3.1 Identification of halal meat supply chain risks

To ensure a comprehensive and context-specific identification of halal meat supply chain risks, this study employed a two-step approach that combined a systematic literature review with expert validation through FGD. The literature review provided an initial compilation of commonly cited halal-related supply chain risks. This list was then validated, refined, and contextualised through an FGD involving the Head of RPH-R and two certified Halal Supervisors. These experts were selected for their direct operational responsibility and practical insights, ensuring relevance and accuracy of the identified risks. During the FGD, each risk was critically evaluated for relevance, frequency, and severity based on the operational realities at RPH-R Bangkalan.

Through this process, 38 distinct risk-enabling factors (REFs) were finalised and classified into three major dimensions: sourcing-related risks (4 REFs), Production-related risks (28 REFs), and Distribution-related risks (6 REFs). The high number of risks under the production dimension reflects the complex and sensitive nature of halal slaughtering operations, which encompass multiple critical points such as pre-slaughter animal handling, compliance with Islamic principles during slaughter, and post-slaughter hygiene and segregation. The dominance of production risks was not only anticipated based on literature but also reinforced during FGD sessions, where experts repeatedly emphasised operational challenges and regulatory non-compliances observed on-site.

To enhance clarity and transparency, the full risk taxonomy is presented in Table 2. In contrast, a visual summary of risk distribution across dimensions is provided in Figure 2. This visual mapping helps illustrate the relative concentration of risks, supporting a better understanding of areas requiring priority intervention.

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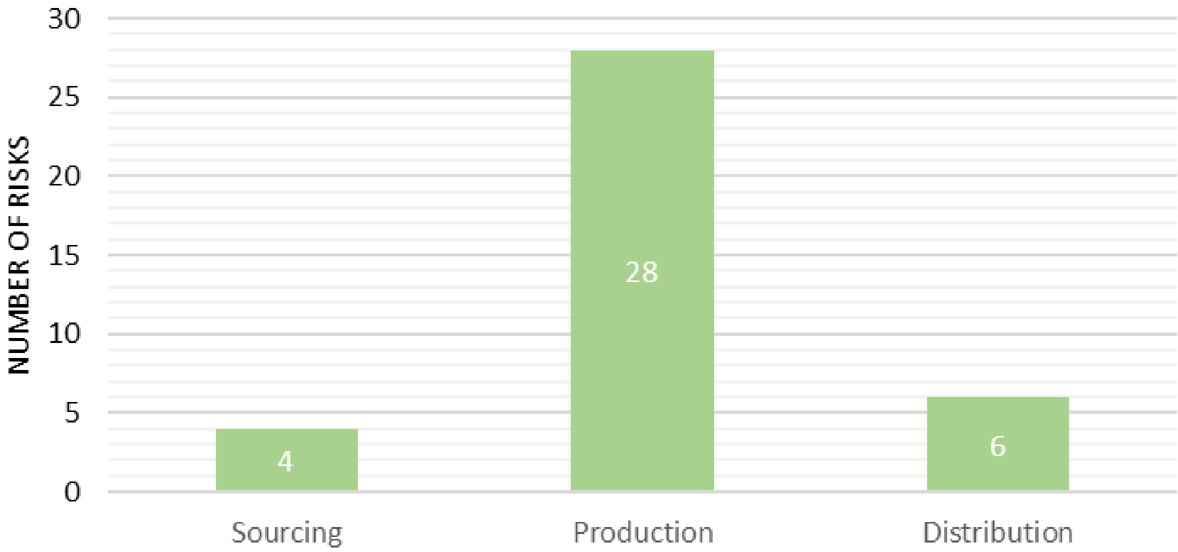

Figure 2 Identified Risks Across Supply Chain Dimensions

3.2 Risk assesment using the best-worst method

The Best-Worst Method (BWM) is solved by minimising the maximum absolute difference between the weight ratios and the expert preference values through a linear programming model, as shown in Equation (1). where W_B and W_w represent the weights for the best and worst criteria, respectively, and a_{Bj}, a_{jw} do experts provide the pairwise comparisons. The objective $\tilde{\xi}$ reflects the consistency ratio of the model, where lower values indicate higher consistency in expert judgments. In this study, all $\tilde{\xi}$ values were ≤ 0.1, ensuring acceptable judgment consistency as Rezaei [27].

This study uses BWM for risk assessment. The results of 38 risks identified from the FGD results are presented in

Table 2 2. In determining numerical preferences, the best and worst risks are identified using BWM numerical values. Table 1 presents the numerical values used in the BWM approach. The numerical preferences between the best and worst risks are displayed gradually in several tables. Table 3 presents the numerical preference results at the risk dimension level, while Table 4 displays risk preferences at the risk aspect level.

Furthermore, Table 5 shows the numerical preferences for the risk enabling factor (REF) at the sourcing dimension. Table 6 to Table 8, respectively, present the numerical preferences at the pre-slaughter (A1), slaughter (A2), and post-slaughter (A3) aspects. Then, Table 9 presents the best and worst numerical risk preferences for REF at the distribution dimension. All these preferences form the basis for calculating risk weights using the Best-Worst Method (BWM) through the implementation of Equation (1). The optimal weighting process was conducted using LINGO software, and the final results are presented in Table 10. Figure 3 presents a graph that summarises the ranking according to global weights. Furthermore, the pareto analysis can be seen in Figure 4 and Table 11.

Table 2 Halal meat supply chain risk

Risk Dimension	Risk Aspect	Risk Enabling Factor (REF)	Reference
Sourcing Related Risk (S)		Animal not alive at the time of slaughter (S1)	[29], [30]
		The animal does not meet health standards (S2)	[29], [30], [31], [32], [11]
		An animal fed with feed containing pork, haram, or impure substances (S3)	[29], [30], [13]
		Incomplete information about the delivered cattle (S4)	Puška, et al. [33], [31]
Production Related Risk (P)	Pre-slaughter (A1)	Vehicles unsuitable for transporting animals (P1)	[29], [30]
		Animal data is not properly documented (P2)	[29], [30]
		Antemortem examination (animal health before slaughter) is not carried out (P3)	[29], [30]
		Animals see other animals being slaughtered (P4)	[29], [30]
		Knives are sharpened near animals (P5)	[29], [30]
		Lack of trained personnel in handling livestock (P6)	[29], [30]
		Livestock handling methods do not consider animal welfare (P7)	[29], [30]
		Slaughter facilities are prone to contamination (P8)	[31], [9], [32]
		Inadequate water supply (P9)	[31], [8]
		Animal holding pens do not meet standards (P10)	Expert
	Slaughter (A2)	Failure to recite the basmalah (tasmiyah) during slaughter (PP1)	[29], [30], [31], [32]
		Incomplete severing of the food and respiratory tracts (PP2)	[29], [30], [31], [9], [32], [13]
		Slaughtering was not performed quickly (PP3)	[29], [30]
		Death did not occur as a result of slaughter (PP4)	[29], [30]
		The slaughterer does not know the process of slaughter according to Islamic law (PP5)	[31], [32], [11]
		The slaughterer does not follow the SOP (PP6)	[31]
		The knife is not sharp and not food grade (PP7)	[29], [30], [31], [8], [32], [11]
		Knife size is inappropriate (PP8)	[29], [30]
		Knives made from prohibited materials (bones, nails, horns, teeth) (PP9)	[29], [30]
		Slaughtering tools that are not hygienic (PP10)	[31]
		Equipment prone to corrosion (PP11)	[29], [30]
		Slaughterers do not have halal slaughterer certificates (PP12)	Expert
	Post-slaughter (A3)	Handling is carried out before the death of the animal is confirmed (PPP1)	[29], [30], [31], [8]
		Post-slaughter animal health inspection is not performed or is invalid (PPP2)	[29], [30]
		Non-compliant results are not separated (PPP3)	[29], [30]
		Cut meat is placed on the floor (PPP4)	[34], [8]
		The presence of blood residue on meat (PPP5)	[31], [9], [32], [11]
		Improper meat aging (PPP6)	Expert
Distribution Related Risk (D)		Not using appropriate transportation (D1)	[29], [30], [32], [11]
		No clear agreement (D2)	[29], [30]
		Halal certificate copies not displayed (D3)	[29], [30], [7]
		Incomplete or missing documents (D4)	[29], [30], [7]
		Unpackaged slaughtered meat is contaminated (D5)	[29], [30], [34], [35],
		Insufficient cleaning of transport vehicles before use (D6)	[35], [7]

Table 3 Numeric preferences risk dimension best and worst risk

BO	S	P	D
Best Dimension risk: P	3	1	6
OW			*Worst Dimension risk*: D
S			3
P			7
D			1

Table 4 Numeric preferences risk aspect best and worst risk

BO	A1	A2	A3
Best Aspect risk: A2	4	1	2
OW			*Worst Aspect risk*: A1
A1			1
A2			3
A3			2

Table 5 Numeric preferences REF dimension sourcing best and worst risk

BO	S1	S2	S3	S4
Best risk: S4	7	2	4	1
OW				*Worst risk*: S1
S1			1	
S2			6	
S3			4	
S4			7	

Table 6 Numeric preferences REF aspect Pre-slaughter best and worst risk

BO	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Best risk: P3	6	5	1	4	8	4	2	5	7	6
OW										*Worst risk*: P5
P1						5				
P2						3				
P3						8				
P4						3				
P5						1				
P6						4				
P7						2				
P8						4				
P9						4				
P10						5				

After obtaining the local weights for each risk at the enabling factor level, global weights were derived by multiplying the dimension weight (a), aspect weight (b), and local REF weight (c). This hierarchical aggregation enables an integrated evaluation of risk dimensions from broad to specific risk sources. The halal meat supply chain (HMSC) is inherently vulnerable due to the perishable nature of meat, which is susceptible to contamination, microbial growth, and rapid spoilage [36]. The risk assessment results indicate a predominance of production-related risks (P) with a weight of 0.66, consistent with prior findings that emphasise production as the most critical control point in halal assurance [31].

A comparative analysis of risk weights reveals that the risk of incomplete information about the delivered cattle (S4), the top-ranked risk with a global weight of 0.12, originates from the sourcing stage but creates ripple effects throughout the supply chain. The lack of traceability at this early stage impedes inspection, undermines certification, and increases the likelihood of non-halal or unhealthy cattle entering slaughter facilities [37]. This sourcing-related risk is causally linked to production risks, notably non-compliance with slaughtering SOPs (PP6), which also carries a weight of 0.12. While S4 threatens the integrity of inputs, PP6 directly compromises the validity of the process. The simultaneous presence of both risks indicates that weaknesses in both input governance and operational discipline can critically endanger halal compliance. These findings emphasise the need for integrated traceability and procedural standardisation throughout the chain [38].

Table 7 Numeric preferences REF aspect slaughter best and worst risk

BO	PP1	PP2	PP3	PP4	PP5	PP6	PP7	PP8	PP9	PP10	PP11	PP12
Best risk: PP6	7	5	6	8	6	1	6	7	8	6	7	8
OW												*Worst risk*: PP12
PP1							3					
PP2							4					
PP3							3					
PP4							2					
PP5							5					
PP6							8					
PP7							5					
PP8							3					
PP9							2					
PP10							3					
PP11							2					
PP12							1					

Table 8 Numeric preferences REF aspect after-slaughter best and worst risk

BO	PPP1	PPP2	PPP3	PPP4	PPP5	PPP6
Best risk: PPP2	3	1	4	2	2	7
OW						*Worst risk*: PPP6
PPP1				5		
PPP2				8		
PPP3				4		
PPP4				6		
PPP5				5		
PPP6				1		

Table 9 Numeric preferences REF dimension distribution best and worst risk

BO	D1	D2	D3	D4	D5	D6
Best risk: D2	4	1	7	2	5	3
OW						*Worst risk*: D3
D1				4		
D2				7		
D3				1		
D4				6		
D5				4		
D6				6		

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Table 10 Ranking of risk dimensions and risk enabling factors on halal meat supply chain

Risk dimension	Weight dimension (a)	Risk aspect	Weight aspect (b)	Risk enabling factor	Local weight (c)	Local rank	Global weight (a×b×c)	Global rank
Sourcing-related risk	0,24			S1	0.06	4	0.01	24
				S2	0.29	2	0.07	3
				S3	0.15	3	0.04	8
				S4	0.50	1	0.12	1
Production related risk	0,66	Pre-slaughter	0,15	P1	0.06	7	0.01	34
				P2	0.08	5	0.01	32
				P3	0.31	1	0.03	9
				P4	0.10	3	0.01	28
				P5	0.03	10	0.00	38
				P6	0.10	4	0.01	29
				P7	0.14	2	0.01	25
				P8	0.08	6	0.01	33
				P9	0.05	9	0.01	36
				P10	0.06	8	0.01	35
		Slaughter	0,54	PP1	0.06	7	0.02	17
				PP2	0.08	2	0.03	10
				PP3	0.07	3	0.02	12
				PP4	0.05	10	0.02	21
				PP5	0.07	4	0.02	13
				PP6	0.33	1	0.12	2
				PP7	0.07	5	0.02	14
				PP8	0.06	8	0.02	18
				PP9	0.05	11	0.02	22
				PP10	0.07	6	0.02	15
				PP11	0.06	9	0.02	19
				PP12	0.03	12	0.01	27
		Post-slaughter	0,31	PPP1	0.13	4	0.03	11
				PPP2	0.33	1	0.07	4
				PPP3	0.10	5	0.02	20
				PPP4	0.20	2	0.04	5
				PPP5	0.20	3	0.04	6
				PPP6	0.04	6	0.01	31
Distribution related risk	0,10			D1	0.11	4	0.01	26
				D2	0.37	1	0.04	7
				D3	0.04	6	0.00	37
				D4	0.23	2	0.02	16
				D5	0.09	5	0.01	30
				D6	0.15	3	0.02	23

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The third and fourth top risks, animals not meeting health standards (S2) with a global weight of 0.07 and invalid post-slaughter inspection (PPP2) with a global weight of 0.07, suggest a causal chain. Inadequate animal health control (S2) contributes to systemic health risks, which are left unchecked due to ineffective post-mortem inspection (PPP2) [39]. The post-slaughter phase is a key stage in determining meat quality [40]. Authorised inspectors conduct post-mortem inspection to assess the health condition of the offal and carcass after the slaughtering process [41]. These stages form a risk corridor where animal health issues are neither prevented upstream nor identified downstream, amplifying exposure to both halal violations and foodborne illnesses. Lastly, hygiene-related risks, such as placing cut meat on the floor (PPP4) and the presence of blood residue on meat (PPP5), each with a global weight of 0.04, may appear less severe individually. However, their cumulative causal impact, namely the risk of cross-contamination with najis elements, can downgrade an otherwise halal compliant product to *mutanajis* status, rendering it impermissible [42]. Moreover, cross-contamination serves as the primary cause of food poisoning incidents [43]. Therefore, even seemingly minor hygiene lapses have amplified consequences in a halal context, reinforcing the importance of strict facility and worker hygiene protocols.

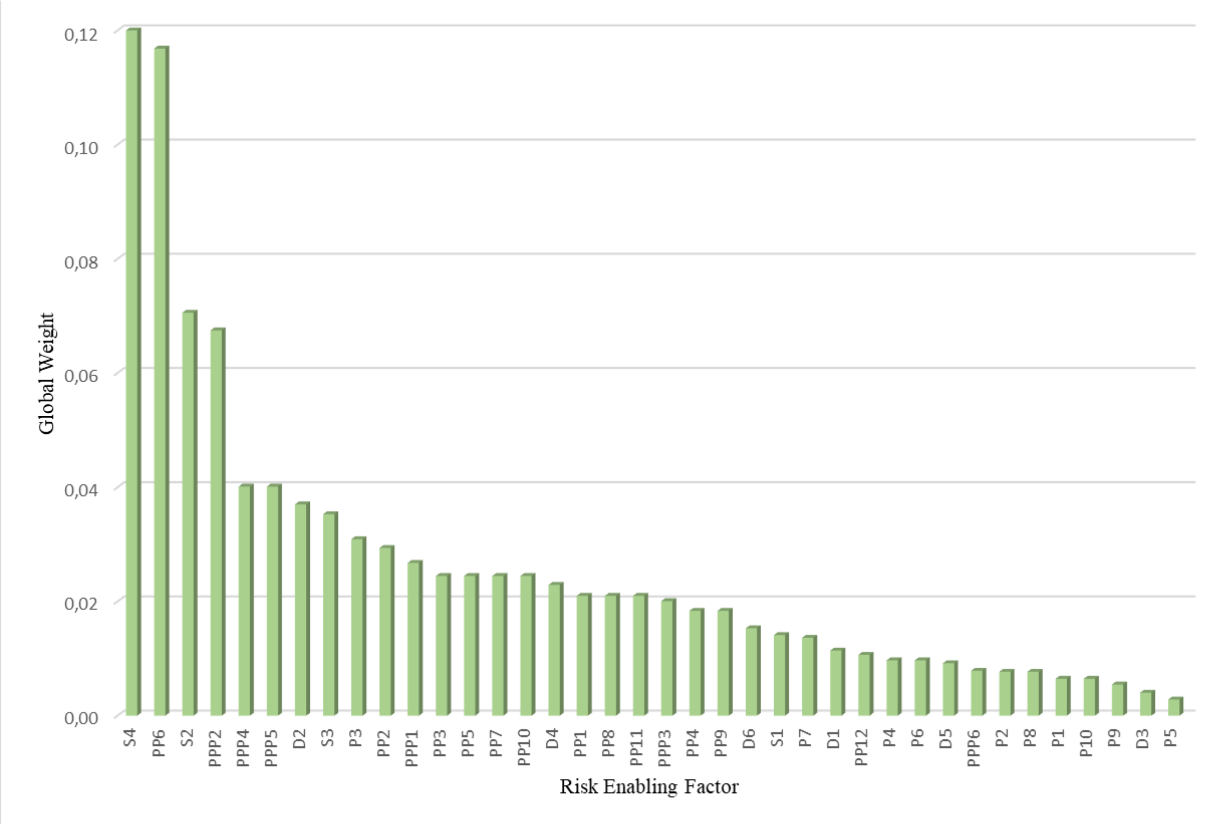

Figure 3 Halal Meat Supply Chain Risks Based on Global Weight BWM

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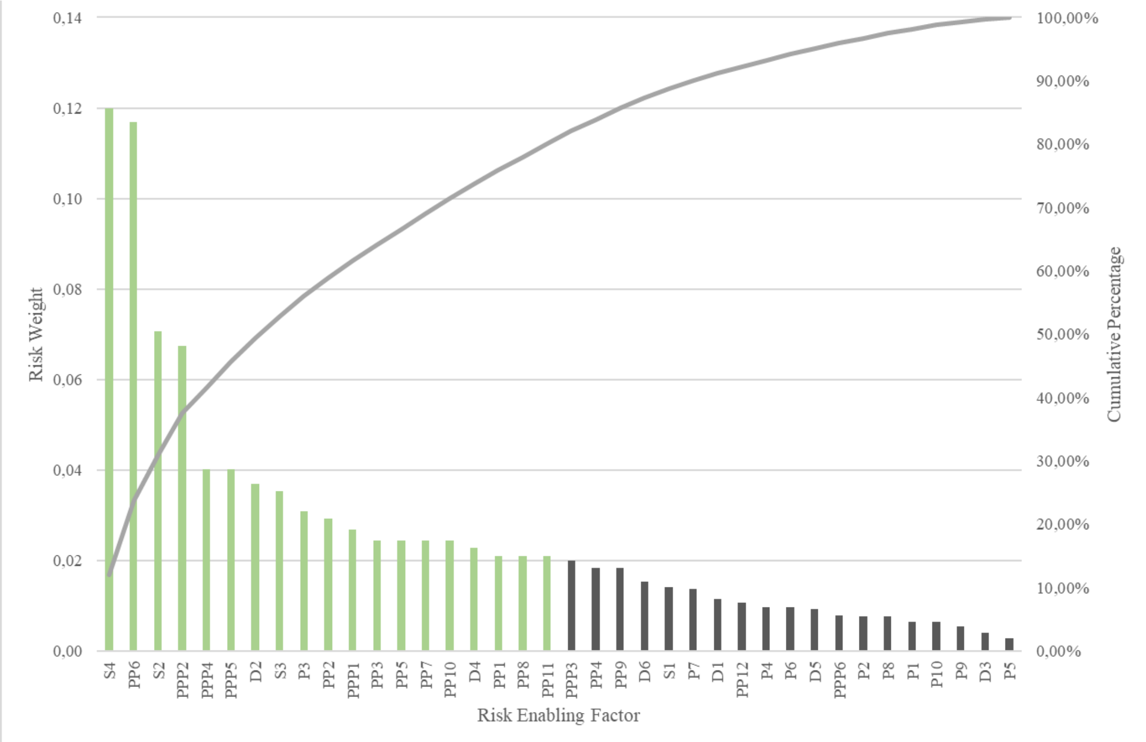

Figure 4 Pareto Chart of Halal Supply Chain Risks at RPH-R Bangkalan

Table 11 REF determination based on Pareto chart analysis results

Risk-enabling factor	Global Weight
Incomplete information about the delivered cattle (S4)	0.12
The slaughterer does not follow the SOP (PP6)	0.12
The animal does not meet health standards (S2)	0.07
Post-slaughter animal health inspection is not performed or is invalid (PPP2)	0.07
Cut meat is placed on the floor (PPP4)	0.04
The presence of blood residue on meat (PPP5)	0.04
No clear agreement (D2)	0.04
An animal fed with feed containing pork, haram, or impure substances (S3)	0.04
Antemortem examination (animal health before slaughter) is not carried out (P3)	0.03
Incomplete severing of the food and respiratory tracts (PP2)	0.03
Handling is carried out before the death of the animal is confirmed (PPP1)	0.03
Slaughtering was not performed quickly (PP3)	0.02
The slaughterer does not know the process of slaughter according to Islamic law (PP5)	0.02
The knife is not sharp and not food grade (PP7)	0.02
Slaughtering tools that are not hygienic (PP10)	0.02
Incomplete or missing documents (D4)	0.02
Failure to recite the basmalah (tasmiyah) during slaughter (PP1)	0.02
Knife size is inappropriate (PP8)	0.02
Equipment prone to corrosion (PP11)	0.02

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3.4 Assessment of risk mitigation alternatives using PROMETHEE

After obtaining the risk weighting results using the Best-Worst Method (BWM) and identifying 19 priority risks through Pareto analysis, the next step involved determining the most effective mitigation strategies using the PROMETHEE method. This Multi-Criteria Decision-Making (MCDM) approach enables a structured comparison of alternatives by evaluating each strategy's performance across the identified risk enabling factors (REFs). Alternative mitigation strategy can be seen in Table 12. The performance evaluation matrix (Table 13) presents quantitative scores assigned to each mitigation alternative in relation to the 19 REFs. These scores were obtained through a Focus Group Discussion (FGD) involving three experts, consisting of one RPH-R Head and two Halal Supervisors. Using a Likert-type scale ranging from 1 (very low contribution) to 5 (very high contribution), the experts individually assessed how effectively each mitigation alternative addresses each of the REFs. These individual assessments were then discussed collectively and consolidated into a consensus-based performance matrix. The final score is derived from the experts' agreement, which serves as the performance score used in the PROMETHEE calculation. This approach ensures transparency and consistency in decision-making while allowing expert judgments to be captured in a structured and quantitative manner. The use of a Likert-type scale enhances interpretability. At the same time, the PROMETHEE method's ranking mechanism supports an objective identification of the most effective mitigation strategies.

Table 12 Alternative mitigation strategy

Code	Mitigation Strategy	Reference
M1	Provide training on slaughtering processes that comply with Islamic law and halal standards.	[31], [32], [34]
M2	Wash slaughtering tools before and after use.	[31]
M3	Inspect the condition of cattle before accepting them from suppliers.	[31], [32]
M4	Check and repair production equipment regularly.	[31]
M5	Sharpen slaughtering tools before use.	[31], [32]
M6	Educate staff on the importance of complying with SOPs.	[31], [34]
M7	Collaborating with suppliers who are aware of the importance of halal and food safety.	[31], [32]
M8	Maintaining the cleanliness of production facilities and production floors by conducting regular cleaning.	[31]
M9	Separating slaughtering tools from tools used for other processes.	[31]
M10	Imposing sanctions on staff who do not comply with SOPs.	[34]
M11	Conducting post-slaughtering inspections by experts.	Expert
M12	Conducting routine monitoring of the slaughtering process.	Expert
M13	Requiring suppliers to provide complete documentation regarding the origin, health, and condition of the cattle.	Expert
M14	Requiring slaughterers and butchers to be halal-certified.	Expert
M15	Allowing sufficient time for complete blood drainage.	Expert
M16	Establishing a written agreement outlining the halal standards and SOPs that must be followed.	Expert
M17	Ensuring that the animal is completely dead before further processing.	Expert
M18	Providing special tables and containers that meet hygienic and food-grade standards.	Expert

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Table 13 Matrix of assessment of mitigation alternatives against REF

Mitigation Alternatives	Risk enabling factor (REF)																		
	S4	PP6	S2	PPP2	PPP4	PPP5	D2	S3	P3	PP2	PPP1	PP3	PP5	PP7	PP10	D4	PP1	PP8	PP11
M1	2	4	2	3	2	3	1	2	3	5	4	5	5	3	2	1	5	4	3
M2	1	2	1	2	3	2	1	1	1	2	1	2	1	3	5	1	1	1	2
M3	5	1	5	2	1	1	2	4	4	1	1	1	1	1	1	3	1	1	1
M4	1	2	1	1	2	2	1	1	1	3	1	3	1	4	5	1	1	4	4
M5	1	2	1	1	1	2	1	1	1	4	1	4	1	5	3	1	1	2	1
M6	2	5	2	3	3	3	2	2	3	3	3	3	3	3	3	2	3	3	2
M7	5	2	5	2	1	1	4	5	3	1	1	1	2	1	1	4	2	1	1
M8	1	2	1	2	5	3	1	1	1	1	1	1	1	2	4	1	1	1	2
M9	1	2	1	1	2	2	1	1	1	2	1	1	1	3	4	1	1	2	2
M10	2	5	2	3	3	3	2	2	3	3	3	3	3	3	3	2	3	3	2
M11	1	2	3	5	3	5	1	1	2	3	2	2	2	1	2	1	1	1	1
M12	2	4	2	3	4	4	2	2	3	4	4	4	4	3	3	2	4	3	3
M13	5	1	4	2	1	1	4	3	3	1	1	1	1	1	1	5	1	1	1
M14	2	4	2	2	2	2	2	2	2	4	3	4	5	3	3	2	5	3	3
M15	1	2	1	2	1	5	1	1	1	2	3	2	2	1	1	1	1	1	1
M16	3	4	3	3	3	3	5	3	3	3	3	3	3	3	3	4	3	3	3
M17	1	2	1	2	1	3	1	1	1	2	5	2	2	1	1	1	1	1	1
M18	1	2	1	2	5	3	1	1	1	1	1	1	1	2	3	1	1	1	2

Furthermore, the results of the alternative mitigation strategy ranking are presented in Table 14. The PROMETHEE analysis identifies five strategies with the highest net flow values, indicating their relative effectiveness across multiple risk-enabling factors (REFs). The top-ranked strategy, M16 (establishing a written agreement outlining halal standards and SOPs), not only received the highest net flow (0.448) but also offers the broadest coverage across organisational, procedural, and supplier-related risks. This strategy enhances compliance through formalised commitments and is highly feasible due to its administrative nature, requiring minimal physical resources or technological investment. The cost is relatively low, primarily involving legal or procedural drafting, making it attractive for SMEs and public facilities such as RPH. M12 (routine monitoring of the slaughtering process), ranking second (0.408), ensures continuous oversight, especially for procedural lapses such as improper slaughter or hygiene issues. It provides medium coverage, focusing mainly on production-stage risks, and requires a moderate investment in terms of labour or staff allocation for inspection duties. However, it offers immediate feedback mechanisms which support rapid corrective action.

M6 (educate staff on SOP compliance) and M10 (impose sanctions for SOP violations) both scored 0.359. While M6 focuses on capacity-building and cultural reinforcement, M10 strengthens accountability and enforcement. M6 has higher feasibility and lower cost, involving training modules and scheduling. In contrast, M10 may face institutional resistance and requires well-defined HR and legal frameworks to be effective. M1 (provide training on Islamic slaughtering practices) ranks fifth (0.318). This strategy focuses specifically on slaughterers and contributes to compliance by improving technical competence and religious knowledge. While cost is moderate due to the need for certified trainers, its targeted nature means coverage is narrower but highly impactful in preventing critical halal violations. This comparative insight clarifies that while all top strategies perform well overall, their trade-offs in terms of coverage breadth, feasibility, and implementation cost should guide selection based on facility-specific needs and constraints. For instance, M16 and M6 may be prioritised in resource-limited contexts. At the same time, M12 and M1 can be emphasised in facilities with sufficient operational capacity.

Table 14 Ranking alternative mitigation strategies

Mitigation Alternatives	Net Flow	Ranking
M16	0.448	1
M12	0.408	2
M6	0.359	3
M10	0.359	4
M1	0.318	5
M14	0.251	6
M7	0.065	7
M11	-0.024	8
M3	-0.059	9
M13	-0.069	10
M4	-0.213	11
M2	-0.232	12
M8	-0.234	13
M18	-0.247	14
M15	-0.265	15
M17	-0.275	16
M5	-0.280	17
M9	-0.309	18

3.5 Implications of this research

The findings of this study contribute to both managerial practice and academic discourse on risk governance in the halal meat supply chain (HMSC). From a managerial standpoint, prioritising critical risks such as incomplete cattle information (S4), non-compliance with slaughtering SOPs (PP6), and health violations provides clear direction for the formulation of targeted operational controls. Management at slaughterhouses (RPH-R) is encouraged to implement risk-based mitigation strategies, supported by documented halal assurance policies, structured training modules, and continuous supervision systems. These efforts should be supported by measurable key performance indicators (KPIs), such as the percentage of cattle accompanied by verified documents, the rate of SOP compliance during slaughter, the frequency of post-slaughter inspections, and the number of staff certified in halal handling.

In terms of policy implications, this study highlights the importance of institutionalising halal risk governance through national standards and effective local government enforcement. Regulators are advised to incorporate risk-based inspection protocols and performance benchmarking into halal certification audits. The inclusion of mandatory KPIs, such as livestock traceability compliance rates, the number of SOP violations per month, and hygiene audit scores, can be used by policymakers to monitor

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and incentivise compliance among certified slaughterhouses. Academically, the study demonstrates the utility of integrating BWM and PROMETHEE to bridge risk assessment and mitigation decision-making in the context of halal. The methodological framework offers a structured, scalable, and reproducible approach that can be applied beyond the specific case of Bangkalan's slaughterhouse. It is adaptable for other sectors within halal supply chains, such as halal cosmetics, pharmaceuticals, or processed food manufacturing, where traceability, compliance, and consumer trust are paramount. Future research may refine the framework by incorporating dynamic risk variables, expanding the expert panels, or comparing effectiveness across different organisational types and regions.

4. Conclusion

This study presents an integrated risk management framework for the halal meat supply chain by combining the BWM for risk prioritisation and the PROMETHEE for strategy selection. This methodological synthesis addresses the complexity and hierarchical nature of HMSC risks, enabling both granular risk assessment and multi-criteria strategy evaluation in a cohesive framework. Unlike prior studies that often focused solely on risk identification or employed single-criterion approaches, this research provides a decision-support structure that links risk weighting to context-specific mitigation strategies, offering a significant advancement over the fragmented assessments found in previous literature. The findings reveal that production-related risks, particularly staff non-compliance with SOPs (PP6), incomplete cattle documentation (S4), and violations of animal health standards (S2) pose the greatest threats to halal integrity. The PROMETHEE-based strategy ranking indicates that establishing written halal agreements (M16), implementing routine slaughter monitoring (M12), and enhancing staff awareness through SOP training (M6) are the most effective countermeasures. These results underscore the importance of risk mitigation that targets both upstream traceability and downstream process control to ensure end-to-end halal assurance.

This research contributes to the academic literature by filling a methodological gap. The integrated application of BWM and PROMETHEE within halal risk management is still underexplored. It demonstrates that a dual-method approach not only increases analytical rigour but also enhances managerial relevance in contexts where ethical compliance is critical. Moreover, the inclusion of expert-derived weights and practical strategy sets rooted in slaughterhouse operations reinforces the model's applicability in real-world decision environments. Strategically, these insights offer valuable guidance for halal certification bodies, policymakers, and slaughterhouse managers. For instance, certification bodies can adopt the proposed model to structure halal audit protocols based on risk severity. At the same time, local regulators can establish performance-based incentives tied to Key Performance Indicators (KPIs) such as SOP compliance rate, traceability coverage, and hygiene audit scores. This ensures that halal assurance is not only procedural but also outcome-oriented. Future research should explore the applicability of this integrated framework across other segments of the halal supply chain, such as halal logistics, halal food processing, or non-meat halal products, and incorporate dynamic variables, including seasonal supply shocks, digital traceability systems, and consumer trust indicators. Furthermore, expanding the expert panel and comparing cross-regional implementations can enhance the model's generalizability and robustness.

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