TRACKING AND TRACING SYSTEMS FOR HALAL PERISHABLE PRODUCTS: A FUZZY AHP AND QFD APPROACH

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ABSTRACT: Given the characteristics of perishable halal products, tracking and tracing are essential for ensuring halal integrity throughout manufacturing and distribution processes. Accordingly, a systematic approach is required to integrate customer needs and halal requirements into the design of a system that accurately tracks and traces halal perishable products. Specifically, the analytical hierarchy process (AHP) and quality function deployment (QFD) can be utilized to design the tracking and tracing system, but both methods suffer from decision-making bias. Meanwhile, fuzzy logic can be incorporated with AHP to reduce ambiguity. However, there is a lack of research integrating fuzzy AHP (FAHP) and QFD into the design of tracking and tracing systems. Therefore, FAHP and QFD were used to identify the most significant scope of the supply chain and the system requirements for tracking and tracing. Data were collected through questionnaires distributed to managers or supervisors in Yogyakarta, Indonesia, representing the frozen food, herbal products, poultry, bakery, fish, and meat sectors to capture a comprehensive perspective across different halal perishable-product sectors. The findings highlight the importance of integrating tracking and tracing technology into distribution activities, which received a final score of 3.831, marking it as the top priority. This finding underscores the critical role of tracking and tracing in preventing cross-contamination, a strategic step toward maintaining halal product integrity.

KEYWORDS: *Halal; Tracking; Tracing; Supply Chain; Perishable Products*

1.0 INTRODUCTION

In managing the production process of perishable products, such as poultry, adherence to halal principles can help producers build customer trust [1]. Furthermore, tracking and tracing are technologies that can enhance efficiency, transparency, and compliance of halal perishable products throughout raw-material handling (inbound logistics), production, and transportation (outbound logistics) [2]. Nevertheless, considering the complexity of supply chain process, lack of standardized data, and the disparity in technology readiness across companies pose challenges to the design of tracking and tracing system, particularly in objectively identifying user needs and defining system specifications. These challenges may ultimately lead to system underperformance [3]. Methodologically, the analytical hierarchy process (AHP) and quality function deployment (QFD) can be utilized to design a tracking and tracing system that meets customer and halal requirements. However, both AHP and QFD have limitations concerning bias in decision-making [4]. To address this issue, fuzzy logic can be integrated with AHP to represent decision makers' preferences more effectively and reduce ambiguity by converting the AHP scale into linguistic variables, such as triangular fuzzy numbers (TFN).

Numerous studies have applied fuzzy AHP (FAHP) and QFD in supply chain management. For example, Ayyildiz et al. [5] applied FAHP and QFD to examine the impact of cultivation practices in the hazelnut industry. Similarly, Ocampo et al. [6] employed FAHP and QFD to design a sustainability product in a vegetable cooking oil case study. Meanwhile, Singh et al. [7] implemented FAHP to create a tracking and tracing system in the construction industry. Moreover, Gupta et al. [8] applied FAHP to analyze the role of traceability in the food supply chain. Finally, Matey et al. [9] adopted FAHP to examine the role and benefits of real-time transparency for the operational performance of a manufacturing company.

However, the previous review of the literature has indicated that implementing FAHP and QFD for designing tracking and tracing systems in the halal perishable products supply chain remains underexplored. Moreover, the characteristics of perishable products necessitate a different approach from those of halal non-perishable products. Specifically, perishable products have a high risk of quality degradation and contamination with *haram* substances due to their short shelf life, sensitivity to temperature changes, and supply-chain complexity, thereby requiring a reliable tracking and tracing system.

The implementation of a tracking system enhances risk monitoring and control in logistics activities while supporting compliance with halal standards. Similarly, the principle of tracing protects consumers from uncertainty in the production process by ensuring end-to-end transparency across the supply chain, from farmers and suppliers to producers and distributors. Without tracking and tracing, however, halal integrity may be compromised. Accordingly, FAHP and QFD can provide a structured approach to prioritizing system requirement (SR) variables for tracking and tracing. FAHP can be used to determine the relative priorities of these requirements, while QFD can be used to translate and align these prioritized requirements with the relevant scope of the halal supply chain for perishable products. Therefore, this study addresses this gap by integrating FAHP and QFD to design a tracking and tracing system for halal perishable-products supply chain that complies with Sharia principles. Accordingly, this study addresses the following two research questions (RQs):

- RQ 1. What are the requirements for implementing a tracking and tracing system in a halal supply chain for perishable products?
- RQ 2. What halal supply chain scope (SCS) has the highest weight in the design of a tracking and tracing system for perishable products?

Building on the preceding discussion, this study aims to identify the key requirements and investigate the most significant factors in implementing tracking and tracing systems within the halal supply chain for perishable products. This study is organized into four sections: first section introduces the study, second section describes the methodology, third section presents and discusses the results, and fourth section concludes the study and provides suggestions for further research.

2.0 METHODOLOGY

2.1 Steps of Analysis

To address the research gap, this study developed a three-step integrated analytical procedure, as shown in Figure 1. Step 1 involved questionnaire design and data collection. Step 2 involved the FAHP weighting process. Finally, Step 3 used the house of quality (HoQ) to relate the SR and SCS variables and integrate these outputs with the FAHP to rank the final weights of each variable for the tracking and tracing system.

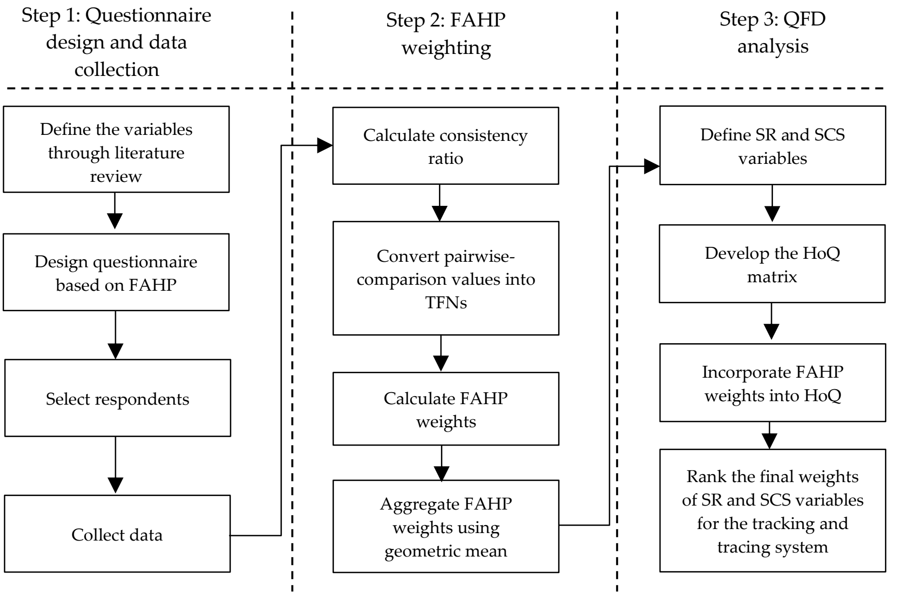

Figure 1: Steps of analysis

2.2 Data Collection

This study employed a case study involving perishable commodities from several sectors, including frozen food, herbal products used in traditional medicine, poultry, baked goods, fish, and meat products, to capture perspectives across diverse perishable-product sectors. These sectors require effective tracking and tracing systems because their products are particularly susceptible to quality degradation and cross-contamination and must comply with halal requirements. All respondents were from Yogyakarta Province, Indonesia, a region known for its relatively developed halal industry. The respondents were managers or supervisors who completed the FAHP and QFD questionnaires and were selected based on their relevant knowledge of their respective companies' operations.

2.3 Variables

Methodologically, this study integrates FAHP and QFD by linking tracking and tracing SR variables, which represent the functional and technical requirements of the system [10], [11], as listed in Table 1, with SCS variables, which represent the relevant operational activities [12], as displayed in Table 2. The two sets of variables are related through the QFD framework to translate customer needs into the tracking and tracing system within the halal supply chain.

Table 1: Tracking and tracing SR variables

Tracking and tracing SR variables	Code
Web and halal information system	SR1
Connectedness between systems	SR2
Global positioning system (GPS)-based tracking	SR3
Database	SR4
Real-time information system	SR5
Business transaction history	SR6
Business performance (Dashboard)	SR7
Barcode	SR8
Radio frequency identification (RFID)	SR9
Internet of things (IoT)	SR10
Data security	SR11
Digital payment systems	SR12
Compatibility between systems	SR13
Verification/validation process	SR14
Cloud technology	SR15

Table 2: SCS variables

SCS variables	Code
Inventory management	SCS1
Procurement	SCS2
Production	SCS3
Product design	SCS4
Scheduling	SCS5
Distribution	SCS6
Transportation	SCS7
Product returns	SCS8
Demand forecasting	SCS9
Customer relationship	SCS10
Sales	SCS11
Marketing	SCS12
Finance	SCS13
Packaging	SCS14
Material handling	SCS15
Quality control	SCS16

2.4 AHP

The steps for calculating the attribute weights using the AHP were as follows [13].

i. Compose a pairwise comparison hierarchy, as listed in Figure 2.

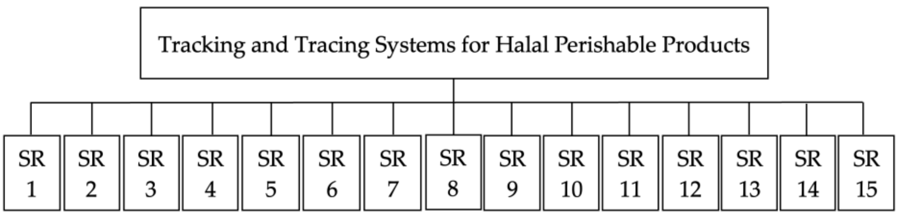

Figure 2: Pairwise comparison hierarchy

ii. Calculate the criteria in a pairwise comparison matrix, as follows.

$$a_{ij}=\frac{w_i}{w_j}\ ,i,\ j=1,2,\ldots,n \tag{1}$$

iii. Respondents completed the AHP questionnaire using a 1-9 scale, ranging from "equal importance" to "extreme importance".

iv. Normalize each column by dividing each element a_{ij} by the sum of its respective column with the following equation.

$$\hat{a}_{ij}=\frac{a_{ij}}{\sum_i a_{ij}} \tag{2}$$

v. Calculate the sum of the normalized values in each row *i*, as follows.

$$\hat{a}_i=\sum_j \hat{a}_{ij} \tag{3}$$

vi. Calculate the weight for each criterion *i*, as follows.

$$w_i=\frac{\hat{a}_i}{n} \tag{4}$$

vii. Calculate lambda max (eigenvalue) of matrix *A*, as follows.

$$\lambda_{max}=\frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i} \tag{5}$$

viii. Calculate the consistency ratio (CR), as follows.

$$CI=\frac{\lambda_{max}-n}{n-1} \tag{6}$$

$$CR=\frac{CI}{RI} \tag{7}$$

The random index (RI) value was determined based on the number of criteria using the corresponding RI table. A CR below 0.1 indicates that the pairwise comparisons satisfy the consistency criterion. The calculated CR values for the six respondents (R) were 0.095, 0.087, 0.096, 0.079, 0.095, and 0.096 for R1-R6, respectively.

2.5 FAHP

This study utilizes TFNs for converting pairwise comparison values from AHP into fuzzy scale values for FAHP, represented by the lower, modal, and upper values (*l, m,* and *u*), respectively, as shown in Table 3 [14]. Compared with trapezoidal fuzzy numbers and normal fuzzy numbers, TFNs can adequately represent decision-makers' preferences under uncertain situations by accommodating the vagueness inherent in subjective judgments, thus making them accurate [15], [16].

Table 3: TFN conversion scale for pairwise comparison values

Pairwise comparison value	Fuzzy scale	Fuzzy scale inverse
1	(1, 1, 1)	(1, 1, 1)
2	(2, 2, 4)	$(\frac{1}{4}, \frac{1}{2}, \frac{1}{2})$
3	(1, 3, 5)	$(\frac{1}{5}, \frac{1}{3}, 1)$
4	(2, 4, 6)	$(\frac{1}{6}, \frac{1}{4}, \frac{1}{2})$
5	(3, 5, 7)	$(\frac{1}{7}, \frac{1}{5}, \frac{1}{3})$
6	(4, 6, 8)	$(\frac{1}{8}, \frac{1}{6}, \frac{1}{4})$
7	(5, 7, 9)	$(\frac{1}{9}, \frac{1}{7}, \frac{1}{5})$
8	(6, 8, 8)	$(\frac{1}{8}, \frac{1}{8}, \frac{1}{6})$
9	(7, 9, 9)	$(\frac{1}{9}, \frac{1}{9}, \frac{1}{7})$

The rules used for TFN operations, namely [14]:
$M_1=(l_1,m_1,u_1)$ and $M_2=(l_2,m_2,u_2)$ rule applies:

$$M_1 \oplus M_1=(l_1+l_2,m_1+m_2,u_1+u_2) \tag{8}$$

$$M_1 \ominus M_2=(l_1-l_2,m_1-m_2,u_1-u_2) \tag{9}$$

$$M_1 \otimes M_2=(l_1 \times l_2,m_1 \times m_2,u_1 \times u_2) \tag{10}$$

$$\lambda \otimes M_2=(\lambda \times l_2,\lambda \times m_2,\lambda \times u_2) \tag{11}$$

$$M_1^{-1}=(\frac{1}{u_1},\frac{1}{m_1},\frac{1}{l_1}) \tag{12}$$

After converting the pairwise comparison values into TFNs, the next step is to perform FAHP analysis as follows [14], [17].

i. Determine the geometric mean of each TFN element in the pairwise-comparison matrix:

$$\widehat{G}_i=(l_1,m_1,u_1) \tag{13}$$

$$l_i=(l_{i1}\otimes l_{i2}\otimes\cdots\otimes l_{in})^{1/n} \tag{14}$$

$i = 1, 2,...,n$

$$m_i=(m_{i1}\otimes m_{i2}\otimes\cdots\otimes m_{in})^{1/n} \tag{15}$$

$i = 1, 2,...,n$

$$u_i=(u_{i1}\otimes u_{i2}\otimes\cdots\otimes u_{in})^{1/n} \tag{16}$$

$i = 1, 2,...,n$

ii. Normalize the criterion or alternative weights using the following equation:

$$\widehat{w}=\frac{\widehat{G}}{\widehat{G}_T}=\frac{(l_i,m_i,u_i)}{(\sum_{i=1}^{n}l_i,\sum_{i=1}^{n}m_i,\sum_{i=1}^{n}u_i)}=\left[\frac{l_i}{\sum_{i=1}^{n}u_i},\frac{m_i}{\sum_{i=1}^{n}m_i},\frac{u_i}{\sum_{i=1}^{n}l_i}\right] \tag{17}$$

iii. Determine the defuzzified value using the following equation:

$$\widehat{w}=\frac{(w_{i,r1},w_{i,r2},w_{i,r3})}{3} \tag{18}$$

iv. Calculate the final weights by aggregating the weights obtained from the six respondents using the geometric mean.

2.6 QFD

The QFD method uses a HoQ matrix as shown in Table 4. The relationships between the SR and SCS variables are evaluated using a three-point QFD scale: 9 indicates a strong relationship, 3 indicates a moderate relationship, and 1 indicates a weak relationship [18].

Table 4: HoQ matrix structure

SR	FAHP Weight (P_i)	SCS (L_j)				
		SCS_1	SCS_2	SCS_3	...	SCS_{16}
A	SR_1	R_{11}	R_{12}	...	...	R_{116}
B	SR_2	R_{21}	R_{22}	...	...	R_{216}
...	...	...	...	...	...	...
n	SR_n	R_{n1}	R_{n2}	...	...	R_{n16}
$ASLDP_j$		$ASLDP_1$	$ASLDP_2$	$ASLDP_3$	...	$ALSDP_{16}$

Description:

$$\overline{R}=\frac{R_1+R_2+R_3\ldots R_n}{n} \tag{19}$$

$$ASLDP_j=\sum_{i=1}^{n}SR_i\times R_{ij} \tag{20}$$

$\bar{R}$ represents the average of QFD relationship score assigned by all respondents for each cell in Table 4. The aggregate value ($ASLDP_j$)

represents the priority score of the corresponding SCS.

3.0 RESULTS AND DISCUSSION

3.1 Results

Based on the FAHP results shown in Figure 3, the real-time information system (*SR_5*) is the highest-weighted requirement for the tracking and tracing system, with a weight of 0.104. The FAHP-derived weight for each requirement was then incorporated into the HoQ, as shown in Table 5.

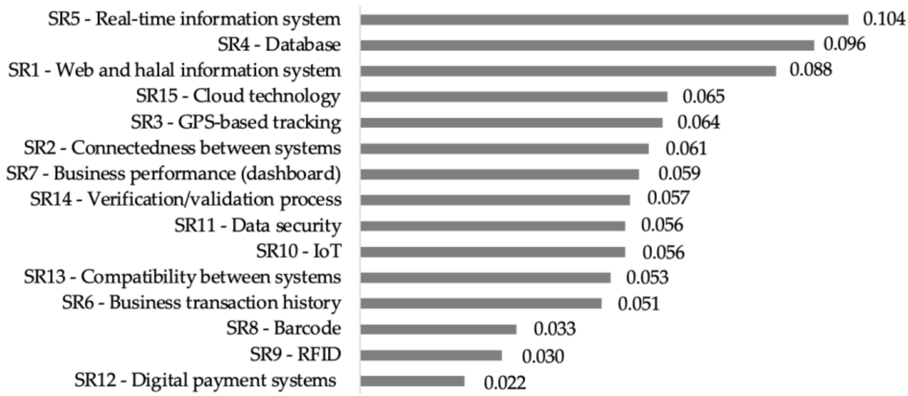

Figure 3: Weight of tracking and tracing SR variables

Based on Equation (20), the final values in Table 5 indicate that distribution (*SCS_6*) aspect is perceived as the most critical factor in implementing tracking and tracing. A sample calculation based on Equation (20) is presented below.

$$\begin{aligned}\Sigma SCS_1 =\ &(0.088\times3.33)+(0.061\times4.67)+(0.064\times1.00)+(0.096\times4.67)+(0.104\times7.67)\\ &+(0.051\times4.00)+(0.059\times3.33)+(0.033\times1.33)+(0.030\times1.00)+(0.056\times2.33)\\ &+(0.056\times3.00)+(0.022\times2.33)+(0.053\times3.33)+(0.057\times2.67)+(0.065\times2.00)\\ &=3.166\end{aligned}$$

Table 5: HoQ of SR and SCS variables

HoQ	Weight (FAHP)	SCS$_{1}$	SCS$_{2}$	SCS$_{3}$	SCS$_{4}$	SCS$_{5}$	SCS$_{6}$	SCS$_{7}$	SCS$_{8}$	SCS$_{9}$	SCS$_{10}$	SCS$_{11}$	SCS$_{12}$	SCS$_{13}$	SCS$_{14}$	SCS$_{15}$	SCS$_{16}$
SR$_{1}$	0.088	3.33	2.67	2.33	2.67	2.67	2.67	1.67	1.33	4.00	3.67	4.33	2.67	2.67	2.67	2.67	1.00
SR$_{2}$	0.061	4.67	3.67	3.33	2.33	3.00	3.67	2.67	3.00	4.00	4.00	3.67	2.33	3.33	3.33	2.67	3.00
SR$_{3}$	0.064	1.00	1.67	2.00	1.33	2.33	4.67	3.67	2.00	2.33	3.00	3.00	3.00	2.33	2.33	2.33	1.00
SR$_{4}$	0.096	4.67	3.33	6.67	3.67	3.00	5.67	2.33	2.00	3.67	5.67	5.67	5.67	5.33	5.33	3.33	3.00
SR$_{5}$	0.104	7.67	4.33	6.33	3.33	4.33	3.67	2.67	2.00	3.67	4.33	4.33	4.33	6.33	4.33	3.00	3.00
SR$_{6}$	0.051	4.00	8.00	6.67	3.33	5.00	6.67	5.33	4.33	4.33	8.00	7.00	6.67	6.33	4.33	3.33	9.00
SR$_{7}$	0.059	3.33	3.33	4.33	3.33	2.67	3.33	3.33	2.33	3.00	4.00	3.67	4.67	5.67	3.33	3.33	9.00
SR$_{8}$	0.033	1.33	1.33	2.33	1.33	2.33	5.00	3.00	2.00	2.33	3.00	5.00	5.00	1.33	3.00	2.33	1.00
SR$_{9}$	0.030	1.00	1.00	1.00	1.00	1.00	1.00	1.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SR$_{10}$	0.056	2.33	3.00	2.67	2.33	2.33	2.67	1.33	1.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	1.00
SR$_{11}$	0.056	3.00	2.33	3.00	2.33	2.00	2.00	2.00	1.00	3.00	5.00	5.00	6.67	3.67	2.00	2.67	3.00
SR$_{12}$	0.022	2.33	2.33	1.33	2.33	1.33	1.33	1.00	2.33	2.33	2.33	2.33	2.33	1.00	1.33	2.33	1.00
SR$_{13}$	0.053	3.33	3.67	3.33	3.33	2.67	3.33	2.00	2.00	2.00	2.67	3.67	3.67	3.67	3.33	2.67	3.00
SR$_{14}$	0.057	2.67	2.00	2.67	2.67	2.33	2.33	2.00	1.67	2.67	3.33	3.33	3.67	1.67	1.33	3.00	1.00
SR$_{15}$	0.065	2.00	2.00	1.33	1.33	1.33	1.33	1.33	2.00	1.33	2.00	2.00	2.00	2.00	1.33	1.33	1.00
SUM		3.166	2.930	3.555	2.701	2.984	3.831	3.174	1.794	2.675	3.446	3.532	3.458	3.262	2.703	2.379	2.512
NORM		0.826	0.765	0.928	0.705	0.779	1.000	0.829	0.468	0.698	0.900	0.922	0.903	0.851	0.706	0.621	0.656
RANK		8	10	2	12	9	1	7	16	13	5	3	4	6	11	15	14

The QFD results are listed in Figure 4. Following distribution (SCS_6), production (SCS_3) is perceived as an essential factor to be integrated with the tracking and tracing system for halal perishable products. In contrast, product returns (SCS_8) has the lowest priority score.

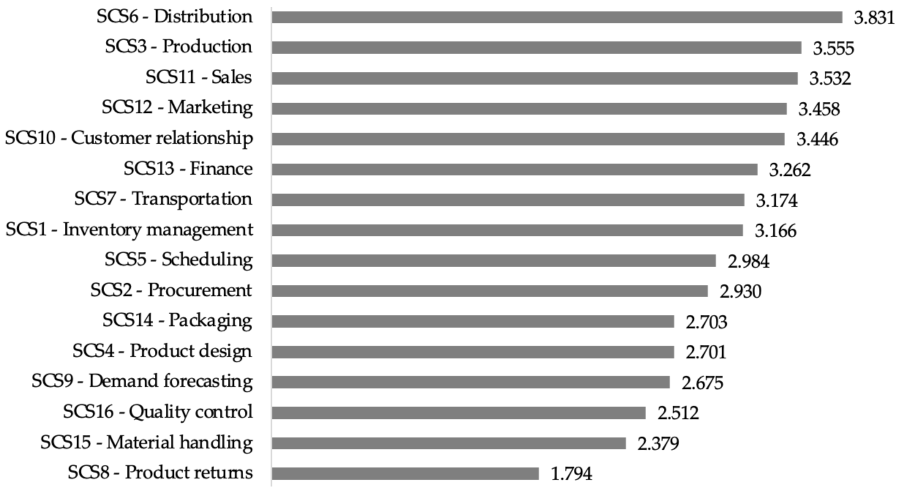

Figure 4: Score of tracking and tracing in the SCS variables

3.2 Discussion

The results indicate that distribution is crucial in the tracking and tracing system. The distribution process involves packaging, picking, storage, transportation, and delivery to end consumers, during which products may be exposed to the risk of quality degradation, cross-contamination, and non-compliance with Sharia principles. In this context, products such as frozen food, herbal products, poultry, baked goods, fish, and meat require specific distribution conditions, including temperature control, cold storage, and dedicated halal facilities. Consistent with the FAHP weighting results, the real-time information system helps monitor the quality of perishable products. Furthermore, the results of this study can be integrated into the proposed framework for tracking and tracing halal perishable products, as illustrated in Figure 5.

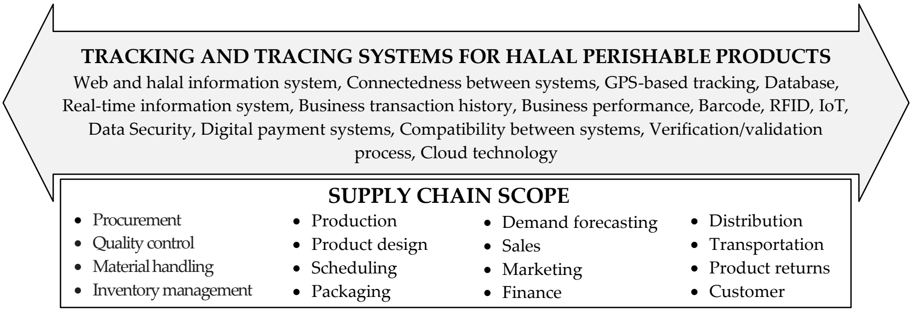

Figure 5: Framework of tracking and tracing

As shown in Figure 5, GPS, RFID, IoT, and cloud technologies serve as the backbone for real-time data exchange and product quality monitoring of the halal supply chain. Blaettchen et al. [19] confirmed that tracing enhances the monitoring, verification, and validation capabilities of supply chain processes. Additionally, previous studies have shown that tracking and tracing improve the quality assurance and halal integrity in beef [20] and chicken [21] supply chains. However, different supply-chain actors typically use different information systems, creating a need for interoperability among these systems. Furthermore, additional technical aspects, such as data security and system integration, must be considered because they may affect the verification and validation process of business transactions. Overall, this study integrates FAHP and QFD to acquire and measure the priority weight of decision-makers' judgments using TFNs and relating these requirements through HoQ. Together, both methods support the design of a tracking and tracing system that addresses the characteristics of perishable products and supports compliance with Sharia principles.

4.0 CONCLUSION

This study provides insights into tracking and tracing through the integration of FAHP and QFD, with real-time information identified as the most essential requirement for the system. This study also reveals that distribution, as part of the halal perishable supply chain, is the most significant factor in implementing tracking and tracing. Real-time information facilitates the planning and monitoring of product flows during distribution activities within the supply chain network, preventing the risk of cross-contamination and quality degradation. Furthermore, one critical aspect that should not be overlooked is that halal products should also satisfy the principle of *tayyib*, which encompasses proper handling and conformity with Sharia principles. In conclusion, adherence to halal standards is crucial for ensuring products' compliance with Sharia principles and preserving the halal integrity of products until they reach consumers. This study demonstrates that tracking and tracing systems can enhance halal integrity throughout the supply chain. However, this study did not examine the architectural design of the tracking and tracing system, including its hardware, software, and human factors. Therefore, further studies should focus on developing and evaluating the system architecture, including cost considerations.

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AUTHOR CONTRIBUTIONS

Y. R. Perdana: Conceptualization, Methodology, Writing-Original Draft Preparation; D. Kristanto: Methodology, Data Collection; N.S.M. Mussafi: Mathematical Validation; E.H. Prasetyo: Writing-Reviewing and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not currently under consideration by other journals. All authors have approved the manuscript, agreed to its submission, and declared that they have no conflict of interest.

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