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Halal Blood Supply Chain Analysis Using the House of Risk Method

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ABSTRACT

The absence of halal assurance mechanisms in blood donation systems presents an urgent challenge in ensuring both medical safety and halal compliance within the blood supply chain (BSC), particularly in Indonesia where over 87% of the population is Muslim. The lack of official halal certification for blood donation poses risks to religious integrity and public trust. Issues such as uncertified materials, inadequate handling supervision, and potential mixing of non-halal blood emphasize the need for a systematic approach integrating medical safety and halal assurance in BSC management. This study contributes theoretically by introducing the concept of a halal blood supply chain and establishing a structured framework for managing halal-related risks in blood donation through the integration of the House of Risk (HOR) model and the Supply Chain Operations Reference (SCOR) framework. Practically, this study offers a risk-based decision support tool for blood service institutions by identifying key halal-related risks and actionable mitigation strategies. Empirically, this research employed the HOR–SCOR framework to identify, assess, and prioritize potential sources of non-halalness in the blood donation operations of PMI Sleman Regency. Data were collected through interviews, observations, and expert validation. The analysis covered 28 risk events and 35 risk agents, quantified using the Aggregate Risk Potential (ARP) and Effectiveness-to-Difficulty (ETD) ratios to determine the most critical risks and appropriate mitigation actions. The results identified four major risk sources: the absence of written halal blood criteria, improper storage temperature, misinterpretation of test results, and machine errors in the crossmatching process. The findings indicate that applying the HOR framework effectively reduces halal-related risks while enhancing operational reliability, transparency, and Shariah compliance within blood donation systems. Furthermore, this study provides a foundation for developing a national halal BSC model and certification system in collaboration with relevant authorities such as BPJPH and MUI.

1. Introduction

The availability of safe and sufficient blood supplies is a public health priority, particularly during emergencies such as accidents, major surgeries, and the treatment of specific medical conditions (Astiwara, 2023). The blood supply chain (BSC) comprises a series of interconnected processes extending from donors to patients, including blood collection, testing, processing, distribution, and

transfusion. The unique characteristics of blood products and the extensive scope of these processes make the BSC highly complex. Factors such as blood type variability, compatibility requirements, and short shelf life further increase this complexity (Cagliano et al., 2022).

Blood transfusion itself is considered a necessary yet high-risk medical intervention. Failure to adhere to appropriate protocols and procedures before, during, and after transfusion may result in severe or even fatal reactions. Transfusions are routinely performed in both intensive care units (ICUs) and general wards, and although the incidence of complications in ICUs may be relatively lower, transfusion-related risks that threaten patient safety remain present in all care settings (Nayeri et al., 2022). Moreover, despite its essential role in healthcare, unsafe blood continues to pose significant health risks. Data from the Indonesian Red Cross (PMI) Blood Transfusion Unit in Surabaya for the period 2018–2022 indicate a substantial prevalence of transfusion-transmissible infections among blood donors, with hepatitis B accounting for 2,148 reactive donors, followed by hepatitis C (1,320 reactive donors), syphilis (1,189 reactive donors), and HIV (807 reactive donors). Additionally, the overall prevalence of transfusion-transmissible infections was highest in 2018 (1,482 reactive donors) and lowest in 2020 (823 reactive donors) (Rees et al., 2024). These cases underscore the need for strict safety and hygiene standards throughout the blood supply process.

Beyond medical safety, the halal aspect of blood transfusion has become increasingly relevant in Muslim-majority countries. Halal originates from the Arabic term *halla*, meaning unbound or unrestricted (Juhari & Gassing, 2025). As a concept rooted in the Qur'an, halal refers to what is permitted under Islamic law and is contrasted with *haram*, which denotes prohibition or unlawfulness (Indarti et al., 2020). In operational terms, halal standards have been widely applied to products and services, including food, pharmaceuticals, and healthcare, as indicators of product integrity, safety, and quality (Tieman, 2011). Previous international studies have demonstrated that halal certification functions as a quality and integrity benchmark beyond religious boundaries, particularly in sectors emphasizing safety, traceability, and risk control, such as food, pharmaceuticals, and healthcare services (Fathi et al., 2016; Tieman, 2011). This perspective positions halal assurance as an indicator of systematic quality management rather than solely religious compliance.

In Indonesia, the importance of halalness cannot be overstated. With a Muslim population of approximately 245.97 million out of a total 282.48 million, it is about 87.08% of the population as of August 2024 (Millie & Baulch, 2024; Thawley et al., 2024). Consequently, halalness is a salient issue in Indonesia. The country ranked third globally in total halal consumption and fifth in halal pharmaceuticals, according to the 2023 Global Islamic Economy Indicator (Ibrahim, 2023). The demand for halal-certified products continues to rise in other sectors, including food, cosmetics, and healthcare (Astiwara, 2023). Despite this prominence, formal halal regulations and authoritative certification for blood donation processes in Indonesia remain absent.

From a supply chain perspective, halal compliance in blood donation extends beyond religious considerations and intersects with health, safety, and ethical risk management. Within halal assurance systems, risk prevention, contamination control, and harm minimization are treated as core compliance criteria, closely aligning halal requirements with established healthcare safety standards and ethical governance practices. Consequently, any stage within the blood supply chain that introduces contamination, unsafe handling, or procedural risk may compromise halal compliance as well as medical safety.

Addressing these intersecting concerns necessitates the involvement of the Indonesian Red Cross (PMI), a humanitarian organization established in 1945 with a mandate to ensure the availability of safe and high-quality blood through its nationwide blood donation units (Triyonoa & Pratiwib, 2025). PMI Sleman Regency, a Blood Donor Unit (UDD) established in 1990, was selected as the study site due to its central role in blood donation services in the Special Region of Yogyakarta. The unit operates through direct and mobile donations, institutional collaborations, and is supported by an official operating license and the Blood Donor Information Management System (SIMDONDAR) for systematic data management. Although PMI Sleman is operationally well equipped, preliminary observations indicate the absence of a dedicated system ensuring halal compliance throughout the

blood donation process, including the use of non-certified additives, potential blood mixing, and insufficiently monitored procedures. These gaps may lead to medical risks and undermine public trust. Accordingly, an integrated approach is required to ensure both medical safety and halal compliance across all stages of the blood supply chain.

Previous studies on the Blood Supply Chain have extensively addressed operational and safety-related risks. For example, Amalina et al. (2024) and Heryanto et al. (2024) applied SCOR-based frameworks combined with FMEA, AHP, and other analytical tools to identify risk sources and design mitigation strategies related to blood availability, storage, and distribution. Similarly, Raras et al. (2020) utilized the House of Risk (HOR) framework to prioritize critical operational risks and propose practical mitigation actions. More recent studies have extended these approaches through the integration of system dynamics, key risk indicators, and multi-criteria decision-making methods (Kalijaga & Handayani, 2022; Sunyoto & Kalijaga, 2024). While these studies contribute significantly to improving operational performance and safety, they do not address halal-related risks within blood supply chain operations.

Research addressing halal risks in supply chains has predominantly focused on food and pharmaceutical products. Studies by Musa & Besar (2025); Qisthani et al. (2023), and Wahyuni et al. (2020) demonstrate that halal risks may arise from both technical and managerial factors, and can be systematically analyzed using frameworks such as SCOR, HOR, HACCP, and FMEA. Related studies in the food industry have also shown that integrating multiple risk analysis methods can strengthen mitigation strategies and improve process control (Shaker & Shahin, 2025; Szczyrba & Ingaldi, 2024; Wang, 2024). However, blood has not yet been examined as an object of halal risk analysis, indicating a significant gap in the halal supply chain literature, particularly in healthcare services where safety, ethical considerations, and public trust are critical.

Based on the existing literature, there is a lack of empirical research that integrates halal compliance into blood supply chain risk management. Specifically, no prior study has systematically identified, assessed, and mitigated halal-related risks in blood donation processes using structured supply chain risk management frameworks. Therefore, this study aims to identify potential sources of halal-related risk within the blood supply chain, assess and prioritize these risks using an integrated HOR–SCOR framework, and propose appropriate mitigation strategies to support halal compliance and medical safety in blood donation operations. This study differs from previous blood supply chain research by explicitly integrating halal compliance into structured risk management analysis. While prior studies have primarily focused on operational efficiency, safety, and availability, none have systematically examined halal-related risks in blood donation processes. By applying an integrated HOR–SCOR framework to blood donation operations, this study extends halal supply chain literature beyond food and pharmaceutical contexts and introduces a novel analytical approach for managing halal-related risks in healthcare services.

2. Method

2.1. Research Design

This study adopts a case study research design focusing on the blood supply chain (BSC) operations of PMI Sleman Regency. The case study approach is chosen to enable an in-depth investigation of operational processes, risk sources, and halal-related issues within a real-world organizational context. This design allows for comprehensive identification and analysis of potential non-halal risks across multiple stages of the blood donation process.

2.2. Research Subject and Object

The subject of this study is the BSC process, while the object of the research focuses on the risk of the emergence of non-halal (non-permissible) elements in the BSC, particularly in blood donors. This research aims to identify potential points where halal-related risks may occur and to determine appropriate mitigation strategies using the House of Risk (HOR) framework integrated with the Supply Chain Operations Reference (SCOR) model.

2.3. Data Collection Methods

For collecting data, there are three methods: observations, interviews, and literature review. Data collection through observation was conducted by directly visiting and observing the research site, examining blood products, tracing the BSC flow, and reviewing the raw materials used in the production of blood units. Interviews were conducted with relevant personnel and staff at the blood bank to gather information regarding the BSC process and the risks present at each stage. The literature review in this study draws from journals, books, conference proceedings, and other scholarly articles to establish the theoretical foundation and references. Sources were accessed through platforms such as Google Scholar, ScienceDirect, Emerald, Semantic Scholar, and others.

2.4. Data Processing and Analysis Method

This study adopts the HOR model to identify and prioritize potential risks of non-halal blood donation process, as well as to develop appropriate mitigation strategies. The House of Risk (HOR) is a framework developed to manage supply chain risks proactively by identifying potential risk events and their causes (risk agents), evaluating their relationships, and prioritizing preventive actions before the risks occur (Puji, 2024).

Additionally, the SCOR framework is utilized to map the supply chain activities involved in the blood donation process. The Supply Chain Operations Reference (SCOR) model is a multifunctional diagnostic tool used to analyze supply chain performance, identify problems, and improve operational efficiency. It integrates concepts from business process reengineering and industry best practices, enabling organizations to evaluate their supply chain's current state and implement targeted improvements to enhance overall effectiveness (Ouyang & Huang, 2024). The application of the SCOR model facilitates systematic risk identification by aligning potential risks with each stage of the supply chain, thereby enabling a more structured and comprehensive analysis.

Within the HOR analysis, risk evaluation is conducted using three main parameters: severity, occurrence, and correlation. Severity reflects the level of impact or consequences that a risk event may have on halal compliance and operational safety if it occurs. Occurrence represents the likelihood or frequency with which a risk agent causes a risk event during the blood donation process. Meanwhile, correlation indicates the strength of the relationship between each risk agent and risk event, showing how strongly a specific cause contributes to the occurrence of a particular risk. These parameters are assessed based on expert judgment. They are subsequently used to calculate the Aggregate Risk Potential (ARP), which serves as the basis for prioritizing critical risks and determining appropriate mitigation actions.

2.5. Expert Selection

To strengthen the identification of halal-critical points and ensure the validity of risk assessment in the blood supply chain, this study involved expert judgment from two perspectives, namely external experts and internal practitioners from PMI. External experts were selected purposively based on the following criteria:

(1) expertise in halal studies, Islamic jurisprudence, or blood donation-related issues;
(2) relevant academic or professional experience;
(3) objectivity and impartiality in assessment; and
(4) the ability to provide reasoned and systematic evaluations related to halal compliance.

The identification and validation of these critical points were derived from the opinions of four external experts, whose profiles are presented in Table 1.

In addition to external experts, internal experts from PMI Sleman Regency were also involved to represent the operational perspective of the blood supply chain. These internal experts comprised PMI personnel responsible for key operational units, including logistics, donor screening and blood collection, Transfusion-Transmitted Infections, component processing, product release, and blood storage and distribution. PMI personnel were selected based on their direct involvement in daily blood donation operations, understanding of procedural workflows, and responsibility for decision-making within their respective units.

Table 1. Expert profile

Expert	Institutional	Area of Expertise / Source of Halal Reference	Year
1	Indonesian Council of Ulama (MUI), Yogyakarta	Direct expert interview (halal jurisprudence and blood donation issues)	2025
2	Faculty of Islamic Studies, Universitas Islam Indonesia (UII)	Direct expert interview (Islamic jurisprudence and halal assessment)	2025
3	KU Leuven	Literature-based expert reference: The Ongoing Charity of Organ Donation: Contemporary English Sunni Fatwas on Organ Donation and Blood Transfusion (Van & Broeckaert, 2011).	2011
4	University of Kiai Haji Achmad Siddiq Jember	Assessing the Istislahiah Method in Islamic law: Study of The Utilization of Science in Ushul Fiqh in The Context of Indonesian Fiqh (Bahiyah, 2024).	2024

2.6. Data Validation

To ensure the validity and reliability of the data used in this study, a multi-step validation strategy was employed. First, the identification and assessment of risk events and risk agents were reviewed through iterative discussions with experts and PMI personnel involved in the blood donation process. This rechecking process aimed to confirm the relevance, clarity, and consistency of the severity, occurrence, and correlation scores assigned during the HOR analysis. Second, the results of data processing, including the prioritization of risks based on ARP and the selection of mitigation strategies using the Effectiveness-to-Difficulty (ETD) ratio, were discussed with PMI representatives. This step served as practical validation to ensure that the analytical outcomes aligned with actual operational conditions and constraints within PMI Sleman. Through these discussions, feedback from PMI practitioners was used to refine the interpretation of results and to assess the feasibility of the proposed mitigation actions. This approach enhances the robustness of the findings by combining expert judgment with organizational insights, thereby strengthening both analytical rigor and practical relevance.

2.7. Research Ethics

This study adhered to standard research ethics principles. Participation in interviews and expert assessments was voluntary, and informed consent was obtained prior to data collection. All responses were treated confidentially and used solely for research purposes, with no personal identifiers disclosed. The study involved no clinical intervention and posed no risk to participants.

3. Results and Discussion

3.1. Halal Definition in the Blood Donation Process

In Islamic jurisprudence, the permissibility (halal) of any practice is assessed within the framework of Shariah, whose ultimate objective is the preservation of human life and social order through the protection of five essential dimensions (*al-daruriyyat al-khams*): religion, life, intellect, lineage, and wealth. These objectives, conceptualized as *maqasid al-shariah*, are generally categorized into securing benefits, preventing harms, and averting disasters for human beings in both worldly and spiritual contexts (Maulida & Ali, 2023). Through this framework, Shariah seeks to realize public welfare (*maslahah*) by maximizing benefits and minimizing potential harm, as articulated by classical scholars and reaffirmed in contemporary halal system analyses (Hilme & Raffi, 2024).

In the context of blood donation, the principle of preserving life (*hifz al-nafs*) becomes the primary *maqasid* that must be upheld. This priority necessitates a critical examination of potential non-halal elements that may emerge throughout the blood donation process. However, such risks cannot be systematically identified or managed without first establishing a clear and conceptually grounded definition of halal and the criteria that govern it within this specific context. Previous studies on halal supply chains emphasize that achieving *maqasid al-shariah* extends beyond procedural compliance and requires explicit articulation of halal principles as a foundational reference for risk identification and decision (Kurniawati & Cakravastia, 2023).

Empirical evidence further shows that the absence of formally articulated halal criteria constitutes a systemic risk, often leading to fragmented and reactive risk management practices (Hilme & Raffi, 2024). This concern aligns with *maqasid*-based sustainability research, which argues that halal assurance must integrate ethical, legal, and societal dimensions rather than relying solely on operational controls (Showole et al., 2025).

In Indonesia, blood services are regulated under Law No. 17 of 2023 and Minister of Health Regulation No. 91 of 2015, which prioritize voluntariness, non-commercialization, and medical safety (Rusmiyanti et al., 2025). However, these regulations remain predominantly operational and provide limited guidance on Shariah-based ethical considerations. As noted, before, unresolved issues related to donor rights, access, and the potential commodification of blood continue to raise ethical concerns in Muslim-majority contexts, where sincerity (*ikhlas*) and the prohibition of trading human body parts are fundamental Islamic principles.

In blood donation practices, the *maqasid* objective of preserving life (*hifz al-nafs*) is paramount. Nevertheless, existing discourse largely focuses on technical procedures, with insufficient attention to the conceptual definition of halalness in medical contexts. This gap mirrors findings in Islamic bioethics literature, which stress that practices involving blood require explicit Shariah-based justification grounded in *maqasid* principles (Talebe et al., 2025). Without a clear halal framework, the identification of non-halal risks remains fragmented and predominantly operational. Therefore, this study addresses this gap by proposing a halal critical point framework for systematically identifying and evaluating non-halal risks in the blood donation process.

Table 2. Halal critical point code

Stage	Potential HCP	Kode
Donor Selection and Collection	Donor is in poor health condition	CH1
	There is an element of coercion	CH2
	There is harm to the donor	CH3
	Blood collection poses a danger to the donor	CH4
Processing and Testing	The presence of infectious diseases and bacteria in the blood	CH5
Storage	Not sterile, contaminated with bacteria and diseases	CH6
	Excessive use of blood	CH7
	Blood donation and transfusion not conducted in emergency conditions	CH8
Distribution and Usage	There is a commercial transaction involving blood	CH9
	There is harm to the recipient	CH10
	Blood is dangerous for the recipient	CH11

Based on Table 2, halal critical points (HCPs) may emerge at every stage of the blood donation process, including donor selection and collection, processing and testing, storage, and distribution and usage. This finding is consistent with previous blood supply chain studies that highlight the presence of safety, ethical, and quality risks across multiple operational stages rather than at a single point in the process (Hossain et al., 2022; Singh et al., 2024). While these studies primarily focus on donor safety, ethical concerns, and transfusion outcomes, the present study extends their implications by interpreting such operational vulnerabilities as potential halal-related risks when evaluated under Islamic principles of contamination prevention, traceability, and harm avoidance.

Risks related to microbiological contamination, testing accuracy, storage conditions, and distribution handling identified in this study align with prior research emphasizing the critical role of environmental control, equipment reliability, and process standardization in blood supply chains (Mitra et al., 2025; Ramirez-Arcos et al., 2023). From a halal perspective, these operational weaknesses may compromise the halal integrity of blood services due to the absence of explicit halal criteria and traceability mechanisms, a gap that has not been addressed in conventional blood supply chain research.

Unlike existing studies that focus on optimizing blood supply chain performance, clinical outcomes, or network design in Alshalani et al. (2022), this study provides a novel contribution by systematically identifying halal-related risks using an integrated HOR–SCOR framework.

Furthermore, Islamic ethical perspectives on blood transfusion support the necessity of structured safeguards to ensure both medical safety and Shariah compliance (Talebe et al., 2025). Therefore, this research not only corroborates prior findings on operational risks in blood supply chains but also extends them by introducing halal assurance as a complementary risk dimension in healthcare services.

3.2. Blood Supply Chain (BSC)

The BSC is a healthcare-specific application of supply chain management that focuses on coordinating the movement of materials, information, and financial resources related to blood products across healthcare organizations (Sunyoto & Kalijaga, 2024). The primary objective of the BSC is to ensure the availability of a safe and sufficient blood supply while managing its inherent complexity and associated costs (Hossain et al., 2022). According to the Siswanto et al. (2025), the efficiency of the blood supply chain depends on regular donor participation, seasonal variations such as holidays, the ability to forecast annual demand, physicians' awareness of transfusion protocols, and hospitals' laboratory capacity to manage blood inventories. The blood supply chain consists of four key stages: collection, production, storage, and distribution. Blood is first collected, then tested and processed into components, stored under strict conditions due to its perishability and compatibility needs, and finally distributed to blood centers, facilities, and hospitals (Amalina et al., 2024).

In order to determine the supply chain activities at blood banks, we employ the SCOR model version 14.0 as an analytical framework, as it allows for the systematic identification and assessment of potential risks throughout the BSC. The SCOR 14.0 outlines six key supply chain stages: plan, order, source, transform, fulfill, and return. Table 3, presents an overview of how these stages are implemented in the BSC.

Table 3. BSC processes

Major Process	Sub-Process	Code
Plan	Planning of equipment and supporting materials for blood donation	C1
Order	Receiving blood order information from the hospital	C2
	Procurement of equipment and materials used	C3
	Receiving and inspection of materials	C4
	Storage of equipment and materials	C5
Source	Registration process of prospective blood donors	C6
	Health screening process of prospective blood donors	C7
	Blood collection process from donors	C8
	Inputting QR data on blood bags	C9
	Delivery process of to IMLTD Room and Component Room	C10
	Blood type, antigen, and antibody testing process	C11
	Blood sorting process in the Component Room	C12
Transform	Weighing process of blood in the Component Room	C13
	Blood separation process in the Component Room	C14
	Product release process	C15
	Storage process	C16
Fulfil	Cross-matching process between donor blood and patients	C17
	Delivery of blood according to procedure	C18
Return	Return of defective raw materials	C19

3.3. Risk Potential

Risk is essentially an element of uncertainty that can lead to negative outcomes for individuals, organizations, or systems. It represents the possibility that an unexpected event will occur and adversely affect objectives, operations, or performance. In business and supply chain contexts, risk arises from unpredictable factors such as market fluctuations, operational failures, or external disruptions. It is also characterized as vulnerability, uncertainty, disruption, disaster, peril, or hazard (Li et al., 2023; Yang et al., 2023). At Risk Potential stage, risk events and their sources are identified before moving on to the next phase, which involves the formulation of prevention actions. The identification of potential risks is carried out using the HOR Phase 1 method, which includes the

identification of risk events and risk agents, risk assessment involving the evaluation of severity, occurrence, and correlation levels, as well as the calculation of the ARP value. The ARP score is used to determine the priority of risk agents. The following steps are undertaken during this phase.

1. Risk Identification

This stage was conducted through direct observation of the blood bank and discussions with experts, including staff members from each department and the person in charge of the blood bank. These interactions aimed to identify potential risks and their underlying causes in the emergence of danger or non-halal aspects. Table 4 below presents the results of the risk events at the blood bank.

Table 4. Risk event and risk agent

Process	Risk Event	R.E Code	HCP	Risk Agent	R.A Code	HCP
C1	Poor quality of blood donor equipment and supporting materials	E1	CH5	Each division is less thorough in identifying the quality aspects needed	A1	CH5
C3	Non-conformity of tools and materials delivered by the supplier	E2	CH4	Suppliers do not pay proper attention to the specifications requested	A2	CH4
C4	Substandard materials are still used	E3	CH4	Quality Control is not comprehensive	A3	CH4
				Human Error	A4	CH4
C5	Expired blood donor support materials	E4	CH4	Storage of materials does not apply the FIFO and FEFO systems	A5	CH4
	Pre-use equipment and material damage	E5	CH4	Lack of proper safety and hygiene in storage areas	A6	CH5
				Damage to equipment and materials during distribution	A7	CH4
C6	Blood donor candidates who provided inconsistent or incorrect personal and medical details	E6	CH1, CH5, CH10	Human error by donor candidates	A8	CH5, CH9
				Lack of confidence among donor candidates regarding their true health condition	A9	CH1, CH4
	Donors feeling pressured to donate blood	E7	CH2	Blood donors who are forced to donate blood due to the influence of others or situational factors	A10	CH2
C7	Missed aspects in health check-ups	E8	CH3	Human error by nurse	A11	CH3
	Inaccuracies in blood group determination	E9	CH10	Health test instruments not properly calibrated	A12	CH4
				Misinterpretation of test result	A13	CH10
	Infected blood donation site	E10	CH3	Improper sterilization	A14	CH5
	There is swelling in the donor's arm	E11	CH5	Small blood vessels and repositioning of blood collection	A15	CH5
C8	Donors on certain medications	E12	CH10	Prospective donors who forget or are less than truthful in answering questions regarding medication use	A16	CH10
	Damaged equipment	E13	CH4, CH9	Lack of regular equipment inspection	A17	CH4, CH9
	Blood contaminated with bacteria or disease	E14	CH5, CH10	Improper arm cleaning during donation	A18	CH5, CH10
C9	Swapped patient blood bags	E15	CH10	Incorrect data input	A19	CH10
C10	Temperature not in compliance with blood storage requirements	E16	CH5, CH10	The pattern of arranging and providing ice gel is not correct	A20	CH5

Process	Risk Event	R.E Code	HCP	Risk Agent	R.A Code	HCP
C11	Invalid test result	E17	CH10	Malfunctioning testing equipment	A21	CH9
C12	Mistakes in sorting of damaged blood bags	E18	CH10	Human error by component division operator	A22	CH10
C13	Excess blood volume	E19	CH6	Inaccurate scale measurements	A23	CH6
C14	Incomplete blood separation	E20	CH10	Missed criteria in blood separation	A24	CH10
C15	Staff missed the criteria check	E21	CH10	Human error in blood bank inspection	A25	CH10
				There is no written list of criteria for approved blood test result	A26	CH10
	Blood clotting	E22	CH10	Donors on certain medications	A27	CH10
				Damaged anticoagulant in blood bag	A28	CH10
C16	Expired blood product	E23	CH10	Mistake in FIFO application	A29	CH10
				Expiration date checks are still manually, increasing potential human error	A30	CH10
	Damaged blood	E24	CH10	Improper storage temperature	A31	CH6
C17	Mismatch between patient and donor blood	E25	CH5	Human Error in the distribution section	A32	CH5
	Inaccurate test results	E26	CH10	Machine error	A33	CH10
C18	Errors in the blood crossmatch process	E27	CH10	Mistakes in the identification of patient blood samples	A34	CH10
C19	Full defective raw materials storage	E28	CH11	No procedures for handling defective products are carried out	A35	CH11

2. Risk Assessment

After identifying the risk events and risk agents in the blood donation and processing stages, the next step involves evaluating their relative importance through severity, occurrence, and correlation assessments. Severity reflects the magnitude of potential impact arising from each risk event and is measured on a scale of 1 to 10, where higher values indicate more critical consequences. Occurrence represents the likelihood of a risk agent emerging during the blood donation process and is also assessed using a 1–10 scale, with higher scores indicating greater probability.

Subsequently, the relationship between each risk event and its associated risk agents is examined through a correlation assessment. This correlation is measured using a four-point scale (0, 1, 3, and 9), representing no, weak, moderate, and strong correlations, respectively. Based on the severity, occurrence, and correlation values, the Aggregate Risk Priority (ARP) is calculated to determine which risk agents require prioritized preventive actions. The overall distribution of severity, occurrence, correlation, and ARP values is summarized in Table 5.

Each risk event has an associated severity score, each risk agent has an occurrence score, and each risk agent–risk event pair has a corresponding correlation value. These values are then used to calculate the ARP. Once the ARP values are obtained, they are ranked from highest to lowest. A higher ARP value indicates that the corresponding risk agent should be prioritized for the development of mitigation strategies. As seen in Eq. (1) and Eq. (2) The following is an example of an ARP calculation.

$$ARPj = Oj\sum SiRij$$

$$ARP1 = 5\sum((9 \times 8) + (9 \times 5) + (1 \times 7) + (1 \times 6) + (1 \times 9) + (3 \times 8)) = 840 \quad (1)$$

$$ARP2 = 3 \sum ((9 \times 8) + (9 \times 5) + (1 \times 7) + (1 \times 9) + (1 \times 8) + (3 \times 9) + (3 \times 10) + (1 \times 10) + (1 \times 5) = 639 \quad (2)$$

Table 5. HOR phase 1

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A…	A35	Sev
E1	9	9	9	9	9	3	9	0	0	0	1	1	9	3	…	0	8
E2	9	9	9	1	0	0	3	0	0	0	0	0	0	0	…	0	5
E3	1	0	1	0	1	0	0	0	0	0	0	3	0	0	…	0	7
E4	0	0	1	9	9	0	3	0	0	0	0	0	0	0	…	0	9
E5	0	1	9	9	3	1	9	0	0	0	1	1	1	0	…	3	7
E6	0	0	0	0	0	0	0	3	9	0	1	0	0	0	…	0	5
E7	0	0	0	0	0	0	0	3	1	3	0	0	0	0	…	0	8
E8	0	0	0	0	0	0	0	3	3	9	9	0	3	0	…	0	8
E9	1	0	1	0	0	0	0	3	3	0	3	9	9	0	…	0	6
E10	0	0	0	0	0	3	1	3	0	0	3	0	0	9	…	0	8
E11	0	0	0	0	0	0	0	0	1	0	3	0	1	0	…	0	7
E12	0	0	0	0	0	0	0	1	3	0	3	1	3	0	…	0	6
E13	1	1	1	1	1	1	1	0	3	0	1	9	9	1	…	0	9
E14	0	0	0	0	0	1	0	0	0	0	0	0	0	9	…	0	7
E15	0	0	0	0	0	0	0	0	0	0	3	0	3	0	…	0	9
E…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
E28	1	1	9	3	0	0	1	0	0	0	1	0	0	0	…	9	5
Occ	5	3	2	4	1	5	5	6	4	1	2	1	3	2	…	1	
AR	84	63	54	98	21	44	124	66	99				159		…		
P	0	9	4	0	7	5	0	6	6	105	682	567	0	390		66	
Ra	14	23	25	13	31	27	9	21	11	34	20	24	3	28	…	35	

3. Risk Evaluation

After the ARP values are calculated, the next step is risk evaluation. This stage involves determining the priority of risk agents to be addressed through mitigation actions, based on the ranking of ARP values from highest to lowest, as shows in Table 6.

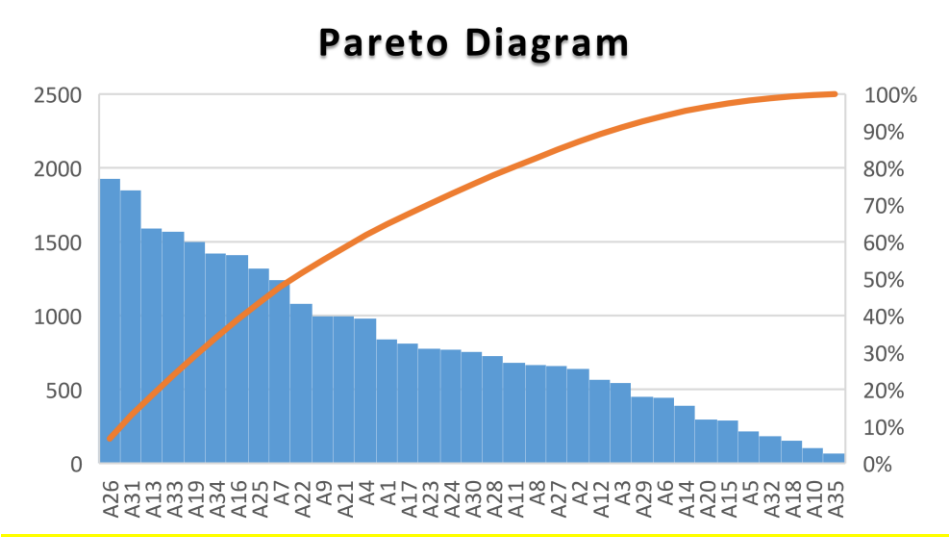

Fig. 1. Pareto diagram

As seen in Fig. 1, the Pareto diagram presents data in descending order, from highest to lowest, displayed from left to right, used to assist in analyzing critical risk areas that require improvement. It focuses on the 80/20 principle, which means that solving 20% of the priority risk agents can influence 80% of the remaining risk agents.

Table 6. Risk evaluation

Rank	Code	ARP	%ARP	%ARP Cumulation
1	A26	1926	6.66%	6.66%
2	A31	1848	6.39%	13.05%
3	A13	1590	5.50%	18.55%
4	A33	1569	5.43%	23.98%
5	A19	1500	5.19%	29.16%
6	A34	1422	4.92%	34.08%
7	A16	1410	4.88%	38.96%
8	A25	1320	4.56%	43.52%
9	A7	1240	4.29%	47.81%
10	A22	1080	3.73%	51.55%
11	A9	996	3.44%	54.99%
12	A21	995	3.44%	58.43%
13	A4	980	3.39%	61.82%
14	A1	840	2.90%	64.73%
15	A17	812	2.81%	67.53%
16	A23	777	2.69%	70.22%
17	A24	770	2.66%	72.88%
18	A30	756	2.61%	75.50%
19	A28	726	2.51%	78.01%
20	A11	682	2.36%	80.37%
21	A8	666	2.30%	82.67%
22	A27	660	2.28%	84.95%
23	A2	639	2.21%	87.16%
24	A12	567	1.96%	89.12%
25	A3	544	1.88%	91.00%
26	A29	452	1.56%	92.57%
27	A6	445	1.54%	94.11%
28	A14	390	1.35%	95.46%
29	A20	297	1.03%	96.48%
30	A15	291	1.01%	97.49%
31	A5	217	0.75%	98.24%
32	A32	185	0.64%	98.88%
33	A18	153	0.53%	99.41%
34	A10	105	0.36%	99.77%
35	A35	66	0.23%	100.00%

Based on the data presented in the Pareto diagram in Fig. 1, four risk agents are identified as the priority mitigation strategies: A26 (absence of a written list of criteria for approved blood), A31 (improper storage temperature), A13 (error in interpreting test results), and A33 (machine error during cross-matching tests). The dominance of A26 further reinforces the earlier finding that halal risks emerge across multiple operational stages. Consistent with prior blood supply chain studies that highlight standardization and procedural control as critical vulnerabilities (Cagliano et al., 2022; Kalijaga & Handayani, 2022; Raras et al., 2020; Sunyoto & Kalijaga, 2024), the present results demonstrate that the absence of formal criteria becomes the most critical risk when these vulnerabilities are evaluated through a halal assurance perspective.

3.4. Strategy Potential

The output from the HOR Phase 1 serves as the foundation for Phase 2. Based on the prioritized risk agents identified in the previous stage, the next step involves formulating proposed preventive actions aimed at reducing or even eliminating the likelihood of risk occurrences. The development of

these mitigation strategies was conducted through iterative discussions with experts and operational personnel from PMI Sleman Regency to ensure feasibility and alignment with existing blood donation practices. The following are the stages in the development of these mitigation strategies.

1. Proposed Mitigation Actions

Table 7. shows the proposed preventive measures.

Table 7. Preventive action

Risk Agent	Code	Preventive Action	Code
There is no written list of criteria for approved blood test result	A26	Preparation of a written list of halal blood criteria	PA1
		Adding personnel to the product release division as needed	PA2
		Rescheduling work and rest times	PA3
Improper storage temperature	A31	Using automatic sensors, temperature alarms, and periodic temperature monitoring SOP	PA4
		Creating a daily temperature inspection schedule with manual recording signed by the officer	PA5
Misinterpretation of test result	A13	Calibration of testing instruments within a specific period and recording of results in a dedicated logbook (inspection section)	PA6
		Placement of a reminder checklist at officers' desks for each initial test	PA7
Machine error in crossmatch process	A33	Calibration of testing instruments within a specific period and recording of results in a dedicated logbook (crossmatch section)	PA8
		Creating an early warning signs list for each tool used	PA9

2. Correlation Assessment

After the proposed mitigation actions are developed, the next step is to assign correlation values between each preventive action and the prioritized risk agents. Similar to HOR Phase 1, the correlation is assessed using a scale of 0, 1, 3, and 9, which represent “no correlation”, “weak correlation”, “moderate correlation”, and “strong correlation”, respectively. Table 7, presents the correlation assessment between the preventive actions and the prioritized risk agents.

3. Total Effectiveness (TEk) Assessment

As seen in Eq. (3), the next step involves calculating the TEk to determine the effectiveness value of each proposed preventive action.

$$TE_k = \sum ARP_j E_{jk} \tag{3}$$

$$TEk = \sum ((9 \times 1926) + (3 \times 1590)) = 18{,}924$$

4. Degree of Difficulty Assessment

The next step is to assess the degree of difficulty to evaluate how challenging each proposed preventive action would be to implement. This assessment uses a scale of 3, 4, and 5, representing “easy to implement”, “moderately difficult to implement”, and “difficult to implement”, respectively. Table 8, presents the difficulty level of each proposed mitigation action.

5. Ratio Effectiveness of Difficulty (ETDk) Assessment

As seen in Eq. (4), after assessing the degree of difficulty, the next step is to calculate the ETDk. This ratio is used to determine which preventive action should be prioritized.

$$\begin{aligned} ETD &= TEk/Dk \\ ETD1 &= 18924 / 3 = 6308 \\ ETD2 &= 1926 / 5 = 385.2 \end{aligned} \tag{4}$$

The Effectiveness to Difficulty Ratio (ETD) represents the comparison between the total effectiveness of a mitigation action (Total Effectiveness/TEk) and the level of difficulty in its implementation (Degree of Difficulty/DK). This ratio is used to evaluate how optimal a mitigation action is by considering the benefits generated relative to the effort or resources required. The higher the ETD value, the more efficient and prioritized the action is considered. The ETD is calculated by dividing the total effectiveness (TEk) by the Dk for each alternative mitigation action. For example, ETD1 has a value of 6308, obtained from dividing a TEk value of 18924 by a difficulty level of 3. This indicates that the first mitigation action has a high level of effectiveness with relatively low implementation difficulty.

Meanwhile, ETD2 has a value of 385.2, obtained from dividing a TEk value of 1926 by a difficulty level of 5. This value is lower than ETD1, indicating that although the action still provides benefits, its effectiveness is relatively lower when compared to the level of difficulty required for its implementation. After completing all necessary calculations, the next step is to construct the HOR Phase 2 table. This table presents the correlation scores between the proposed preventive actions and the potential risk agents, the ARP values obtained from HOR Phase 1, the calculation of total effectiveness (TEk), DK ratings, and the resulting effectiveness-to-difficulty ratios (ETD). This stage also involves ranking the ETD values from highest to lowest to identify which mitigation strategies should be prioritized. Table 8 shows the HOR Phase 2 Table.

Table 8. Table of house of risk phase 2

Code	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9	ARP
A26	9	1	1	0	0	0	0	0	0	1926
A31	0	0	0	3	3	3	0	3	0	1848
A13	1	0	1	0	0	9	3	3	0	1590
A33	0	0	0	0	1	9	0	9	3	1569
Tek	18924	1926	3516	5544	7113	33975	4770	24435	4707	
Dk	3	5	4	3	3	4	3	4	4	
ETD	6308	385,2	879	1848	2371	8493.75	1590	6108.75	1176.75	
Rank	2	9	8	5	4	1	6	3	7	

Based on the data analysis, the prioritized mitigation strategies, ranked according to the highest ETD, are as follows: Calibration of testing instruments within a specific period and recording of results in a dedicated logbook (inspection section) (PA6) with an ETD value of 8493.75; preparation of a written list of halal blood criteria (PA1) with an ETD value of 6308; calibration of testing instruments within a specific period and recording of results in a dedicated logbook (crossmatch section) (PA8) with an ETD value of 6108.75; and Creating a daily temperature inspection schedule with manual recording signed by the officer (PA1) with an ETD value of 2371. This finding is methodologically consistent Raras et al. (2020), who applied the SCOR–HOR framework to blood supply chain risk management and demonstrated that deficiencies in standardization and procedural control constitute dominant risk sources. However, while this research focused primarily on operational efficiency and safety, the present study extends this approach by incorporating halal compliance as a critical risk dimension. The absence of written halal blood criteria thus emerges not only as an operational weakness but also as a fundamental halal assurance risk, affecting traceability, contamination control, and Shariah compliance across the blood donation process.

4. Conclusion

This study demonstrates that integrating halal assurance with proactive risk management through the House of Risk (HOR) framework enhances the reliability, safety, and Shariah compliance of the blood supply chain (BSC). By integrating the HOR and SCOR frameworks, this study systematically identified and prioritized halal-related risks in blood donation processes. The most critical risk sources were the absence of written halal blood criteria, improper storage temperature, misinterpretation of

test results, and machine errors during crossmatching. Based on ARP and Effectiveness-to-Difficulty (ETD) analyses, key mitigation strategies include the development of written halal criteria, instrument calibration, automated temperature monitoring, and systematic documentation. From a scientific perspective, this study extends supply chain risk management literature by introducing the concept of a halal blood supply chain and demonstrating the applicability of the integrated HOR–SCOR framework within a healthcare context. Managerially, the proposed framework provides actionable guidance for blood service institutions, such as PMI, to design operational controls that simultaneously address medical safety and halal compliance. At the policy level, the findings support the development of standardized halal criteria, traceability mechanisms, and future halal certification systems within Indonesia's healthcare sector. This study is limited to a single blood donation unit and relied on expert judgment due to the absence of nationally standardized halal blood criteria. Future research should involve multi-regional studies and collaboration with authorized institutions such as BPJPH and MUI to support the development of formal halal certification and traceability systems.

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