Risk Mitigation Priorities in a Sustainable Pasteurized Milk Supply Chain: A House of Risk Approach in a Small-Scale Dairy Company

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Abstract. The pasteurized milk supply chain plays a strategic role in economic, social, and environmental sustainability, yet is vulnerable to risks at every level. This study aims to identify key risks, prioritize risk agents, and formulate effective mitigation strategies for a pasteurized milk supply chain in Indonesia. The House of Risk was used through a two-stage analysis with input from 9 experts representing farmers, collectors, and processing companies. The mapping yielded 38 risks and 30 risk agents, and a priority assessment was calculated using aggregate risk potential and an effectiveness-to-difficulty ratio. Key findings identified Farmer's error in cattle rearing as the most dominant risk agent with low milk quality and quantity as the next priority. Priority mitigation strategies included education on cattle rearing management, the development of SOPs on farms, and monitoring of on—farm activities. Integrated on-farm activity scheduling and business record-keeping were implemented in the next phase to strengthen efficiency, traceability, and data-driven decision-making. A phased approach focused on the upstream sector increased system resilience, reduced waste, maintained raw material quality, and strengthened partnerships between stakeholders. Practical implications demonstrate the readiness for adoption in small-to medium-scale businesses and the relevance of its application to other fresh food commodities with similar characteristics.

1 Introduction

The pasteurized milk supply chain plays a strategic role in supporting the economy, social welfare, and environmental sustainability in Indonesia. Added value is created through the processing of fresh milk into safe, shelf-stable, and high-value products. The use of technologies such as electric or induction pasteurizers increases efficiency, reduces waste,

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and expands market access. These innovations strengthen the financial sustainability of SMEs and maintain a consistent supply of quality products.

This supply chain sustainability supports job creation, encourages rural economic growth, and builds strong relationships between businesses and local communities. Products that meet food safety standards contribute to public health and increase consumer confidence in domestic products. Consumer behavior in Indonesia, influenced by price, packaging, and perceptions of food safety, demands the distribution of quality products at affordable prices [1].

Environmental aspects require efficient energy and waste management. The implementation of green human resource management and sustainable supply chain management can reduce carbon footprints and increase energy efficiency. Strict sanitation protocols in the pasteurization process reduce the risk of contamination and support responsible waste management.

Sustainability challenges include economic risks due to price fluctuations and limited capital, social risks related to worker welfare and the distribution of benefits, and environmental risks related to resource consumption and emissions. This complexity requires a systematic and adaptive risk management approach. The House of Risk (HOR) method offers a framework for identifying, prioritizing, and managing risks in a measurable manner, although its application in the Indonesian dairy industry is still limited.

Pasteurized milk products, with their short shelf life and susceptibility to contamination, require rapid distribution while maintaining quality. The HOR is relevant for these characteristics to map risk agents and design effective mitigation strategies. This study aims to identify risks in the pasteurized milk supply chain, determine priority risk agents, and develop mitigation strategies that consider economic, social, and environmental dimensions in an integrated manner. The results are expected to strengthen competitiveness, increase resilience to disruptions, and ensure the pasteurized milk supply chain's positive contribution to the economy, society, and environmental sustainability.

2 Research Methods

The research flow used the HOR method combined with visual mapping of the supply chain. This facilitated the identification and analysis of critical points. The research conceptual framework served as a guideline for data collection and analysis.

2.1 Object of Study

This research examines the pasteurized milk supply chain managed by a small and medium-sized enterprise (SME) in Indonesia. The company's characteristics include a medium-scale production with daily capacity adjusted to the availability of fresh milk from local farmers. Business processes include raw material receipt, pasteurization using electric and induction pasteurizers, packaging, storage, and distribution to retail chains.

The main product is pasteurized milk in bottles and cups, with market segmentation targeting retail and institutional consumers. Product complexity includes different package sizes, flavor variations, and shelf-life adjustments to meet market needs. Raw materials are obtained from dairy farmers in the surrounding area through a scheduled collection mechanism by collectors.

The company's position is in an upstream-downstream network involving farmers as suppliers of fresh milk, collectors as aggregators, and the company as a processing and distribution unit to consumers. The scope of the study focuses on these three echelons within the research boundaries, ensuring that the operational context examined remains relevant to the objectives of the risk analysis. Each actor in the supply chain has a specific role that influences quality, supply continuity, and overall system resilience.

A thorough description of the business size, product line, raw material sources, and distribution structure is necessary to ensure methodological transparency and enable replication in subsequent research [2]. Figure 4.1 visualizes the flow of products, information, and finances from upstream to downstream. This visual map highlights the relationships between actors—farmers, collectors, processing units, and distribution channels—and identifies critical points that could potentially pose risks. This aligns with previous research findings that emphasize the importance of visual supply chain mapping for understanding risk transmission pathways and designing targeted mitigation strategies.

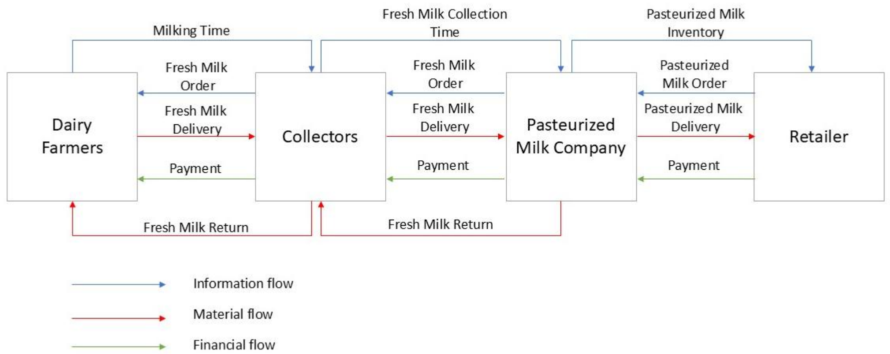

Fig. 1. Supply chain activities at the object of study

Each actor is analyzed in depth to ensure operational details are well documented. At the farmer level, aspects recorded include livestock rearing methods, feeding patterns, cow health management, and milking procedures, all of which affect fresh milk quality. At the collector level, the collection process is described, including pickup frequency, vehicle type, transport capacity, and storage conditions during transportation. For processing units, attention is focused on quality control procedures, pasteurization temperature settings, packaging, equipment calibration, and implementation of food safety standards.

2.2 Data Collection

Data collection combined qualitative and quantitative approaches to obtain comprehensive information related to risk identification, assessment, and mitigation in the pasteurized milk supply chain in this study. Respondents were a panel of experts purposively selected for their extensive track record in supply chain management, milk processing, and risk management. Selection criteria emphasized ongoing professional engagement, extensive experience, and relevant scientific contributions, while ensuring cross-disciplinary representation among practitioners, risk managers, and academics to ensure a balanced assessment of qualitative and quantitative factors [3].

Primary data collection was conducted through structured interviews and questionnaires developed following the House of Risk (HOR) Phase 1 and Phase 2 framework. The initial phase asked 9 expert respondents (representing the dairy farmers, collectors, and pasteurized milk company) to identify risk events and risk agents in the pasteurized milk supply chain activities under study. Each event was assigned a severity and probability of occurrence score, while the event-agent relationship was assessed using a correlation matrix. The next stage assessed the effectiveness of the mitigation strategy, the level of implementation difficulty, and generated an Effectiveness-to-Difficulty (ETD) ratio as a basis for prioritizing actions.

Validation of the assessment results was conducted through controlled feedback iterations, adopting the principles of a modified Delphi method to strengthen assessment consistency and build collective consensus. This step aligns with the approach in perishable supply chain research, which combines expert judgment with quantitative validation techniques through entropy-based weighting calculations, thereby reducing bias and calibrating the resulting risk scores.

Secondary data was collected through a review of company documents, including production reports, distribution records, raw material quality data, and operational disruption records. This information was used to verify the completeness and accuracy of the primary data collection results and to support data triangulation. Combining expert input with historical data is important to ensure the predictive utility of risk assessments in perishable product supply chains [4].

The entire data collection process was conducted with due regard for research ethics. Written informed consent was obtained from all respondents, which included a statement regarding the purpose of the study, data use, and protection of information confidentiality. Corporate and individual identities are anonymized, while data is stored on protected media in accordance with data security procedures. This follows best practices in industry case studies that emphasize methodological transparency while maintaining the confidentiality of sensitive business data.

2.3 Data Analysis

Data analysis was designed to tightly link the HOR Phase 1 output (identification of risk events and agents) with the formulation of mitigation strategies in HOR Phase 2. Interview and questionnaire data were processed into a comprehensive risk list with severity and probability scores. Aggregate Risk Potential (ARP) values were calculated to prioritize risk agents, then visualized using a Pareto chart to clearly identify the proportion of the most dominant factors.

The prioritization results provided direct input to the mitigation phase. Each risk agent was assigned a traceability code so that the link between Phase 1 findings and Phase 2 actions could be tracked and verified. Strategy design considered effectiveness measures and implementation difficulty, ensuring evidence-based decisions aligned with the operational conditions encountered.

Process transparency was enhanced through graphical tools such as Pareto charts and probability-impact matrices, which visually map the identification-mitigation transition. This traceability mechanism maintains accountability, facilitates review as the risk profile changes, and ensures methodological consistency in the continuous improvement cycle of supply chain risk management.

2.3.1 House of Risk Phase 1 (HOR 1)

The Phase 1 HOR analysis organized the identification of risk events and risk agents that impact supply chain performance. A risk event is an occurrence that disrupts operations. A risk agent is a causal factor that increases the likelihood or impact of the event. This separation allows for a more focused assessment and mitigation process. This aligns with the HOR framework, which emphasizes prevention through controlling risk agents [5].

The severity of each risk event (Si) was assessed using a Severity scale with values ranging from 1–10 for the severity of the risk event, ranging from very low to critical. The frequency of occurrence of each risk agent (Oj) was assessed using an Occurrence scale, also with values ranging from 1–10 to distinguish between almost certain and almost certain occurrences. The relationship between risk events and risk agents (Rij) was mapped in the Rij correlation matrix with values of 0 (unrelated), 1 (weak), 3 (moderate), and 9 (strong).

The priority of risk agents was determined by calculating the Aggregate Risk Potential for each risk agent (ARPj). The calculation follows the formula:

$$ARP_j = O_j \sum_i S_i R_{ij} \quad (1)$$

A high ARP value indicates a risk agent that occurs frequently and is strongly correlated with high-impact events, making it worthy of prioritization for management [5].

The quality of the results was maintained through uniform assessment guidelines, briefings for assessors, and inter-assessor calibration on case studies prior to the full assessment. This stage reduces subjective bias and strengthens the accountability of the prioritization procedure for the HOR Phase 2 stage.

2.3.2 House of Risk Phase 2 (HOR 2)

The second stage of the House of Risk (HOR) focused on prioritizing mitigation actions for the risk agents prioritized in HOR 1. This process involved mapping selected risk agents and candidate mitigation actions using three main criteria, i.e. total effectiveness, degree of difficulty, and effectiveness-to-difficulty ratio. This approach ensures that selected actions significantly reduce risk exposure while being realistically implemented within the organization's resource constraints and operational conditions.

Total effectiveness of a mitigation action k (TE_k) describes the ability of a mitigation action to reduce the likelihood of occurrence or impact of the affected risk agent. Assessments were conducted by a panel of experts using an ordinal scale referring to the potential reduction in ARP for one or more risk agents. The relationship between a risk agents j (A_j) and mitigation action k (PA_k) is mapped in the E_{jk} correlation matrix with values of 0 (unrelated), 1 (weak), 3 (moderate), and 9 (strong). If a single action affects multiple risk agents, the TE_k is calculated as follows:

$$TE_k = \sum_j ARP_j E_{jk} \quad (2)$$

This approach ensures resources are directed to actions with the greatest contribution to risk reduction [5].

The degree of difficulty (D_k) reflects the technical barriers, costs, and time required for implementation of a mitigation action k. Assessments are conducted using an ordinal scale with values ranging from 1-10 where low scores indicate ease of implementation and high scores indicate significant challenges.

The relationship between effectiveness and degree of difficulty for of a mitigation action k is represented by the ETD_k ratio, which is calculated using the equation:

$$ETD_k = \frac{TE_k}{D_k} \quad (3)$$

A high ETD_k value indicates that the action provides significant risk reduction benefits per unit implementation challenge. The ETD_k calculation results are used to prioritize mitigation actions, recommending that actions with the highest scores be implemented first. Integration of sustainability reporting standards such as Global Reporting Initiative (GRI) and Sustainability Accounting Standards Board (SASB) enhances transparency, as each mitigation step can be traced to relevant sustainability performance indicators.

3 Results and Discussions

3.1 Risk Identification

Risk identification in the sustainable pasteurized milk supply chain was carried out to understand the specific vulnerabilities affecting farmers, collectors, and processing companies. This process enables each risk to be systematically linked to its underlying causes. Risks are categorized into economic, environmental, and social dimensions, each influencing supply chain resilience and overall performance [6]. Table 1 presents the summary of risks and their associated agents at this stage.

Table 1. Risks and risk agent of the sustainable pasteurized milk supply chain for dairy farmers

Activity	Risk Code	Risk Description	Risk Agent Code	Risk Agent Description
Cattle procurement and rearing	E1	Uncertainty in cattle quality	A1	Farmer's error in cattle rearing
			A2	Farmer's error in cattle selection
	E2	No occupational health and safety assurance during cattle rearing	A3	No employment health insurance program for informal workers
	E3	Uncertainty in feed availability	A4	Long dry season
	E4	Uncertainty in feed price	A5	Low feed stock in the market
	E5	Suboptimal waste management	A6	Worker's error in waste processing
	E6	Cattle rearing not following procedures	A1	Farmer's error in cattle rearing
	E7	No worker contracts	A7	Workers from own family
	E8	Worker age not in accordance with regulations	A8	Family economic factors
	E9	Low worker quality	A9	Lack of work experience
			A10	Low education level
Milking process	E10	Uncertainty in milk production	A1	Farmer's error in cattle rearing
			A11	Low cattle quality
	E11	Uncertainty in milk quality	A1	Farmer's error in cattle rearing
			A11	Low cattle quality
Fresh milk sales	E12	Low collectors satisfaction	A12	Low milk quality and quantity
	E13	Uncertainty in milk selling price	A12	Low milk quality and quantity

Risks at the farmer level are largely driven by production uncertainties, including livestock quality and quantity, feed availability and prices, and suboptimal rearing practices. Farmers remain exposed to input price volatility, livestock diseases, and feed shortages [7]. Social vulnerabilities, such as the absence of occupational health insurance for informal workers and non-compliance with age-related labor regulations, may further reduce productivity.

Collectors encounter a different set of risks, primarily concerning milk quality and safety. Milk sourced from multiple suppliers increases the likelihood of higher aflatoxin M1 levels, compounded by inadequate cold-chain management and weak quality control. Economic risks also emerge from fluctuating prices and inconsistent milk volumes. Table 2 summarizes the risks and their associated causal agents at the collector level.

Table 2. Risks and risk agents of the sustainable pasteurized milk supply chain for collectors

Activity	Risk Code	Risk Description	Risk Agent Code	Risk Agent Description
Milk collection from dairy farmers	E14	Uncertainty in milk availability	A1	Farmer's error in cattle rearing
Quality inspection	E15	Uncertainty in milk quality	A1	Farmer's error in cattle rearing
			A13	Milk damage during transportation
	E16	Suboptimal waste management	A6	Worker's error in waste processing
	E17	Low worker quality	A9	Lack of work experience
			A10	Low education level
Storage	E18	Milk damage during storage	A14	Milk already physically changed
			A15	Tool and machinery damage
Transportation	E19	Milk damage during transportation	A16	Temperature changes in refrigerated trucks
			A17	Experiencing strong shaking during transportation
			A18	Workplace accidents
	E20	Transportation equipment not meeting standards	A19	Low vehicle engine quality
	E21	No occupational health and safety assurance during transportation	A3	No employment health insurance program for informal workers
	E22	Worker age not in accordance with regulations	A8	Family economic factors
Fresh milk sales	E23	Low company satisfaction	A12	Low milk quality and quantity

Risks in pasteurized milk companies include raw material quality, supply sustainability, and compliance with regulatory standards. Variability in milk quality from farmers and collectors is a major challenge. Operational risks include equipment failure, production process errors, and inappropriate workload distribution. Direct company accountability to consumers and regulators adds to the urgency of strict risk control. Table 3 illustrates the mapping of risks and their causal agents at this level.

This integrated risk-agent mapping reveals the different vulnerability profiles of each actor in the pasteurized milk supply chain. Economic factors such as feed prices and raw material availability are dominant for dairy farmers, while quality and safety are central issues at the collector and company levels [8]. This approach facilitates intervention prioritization, where controlling critical risk agents can mitigate multiple risks simultaneously, supporting the sustainability and competitiveness of the supply chain as a whole.

Table 3. Risks and risk agents of the sustainable pasteurized milk supply chain in the pasteurized milk company

Activity	Risk Code	Risk Description	Risk Agent Code	Risk Agent Description
Raw material procurement	E25	Uncertainty in quality of milk supplied by collectors	A13	Milk damage during transportation
			A20	Collector's error in milk quality inspection
Milk quality inspection	E26	Uncertainty in milk availability	A21	Difficulty in obtaining goods
Production process	E27	Milk test results not meeting company standards	A13	Milk damage during transportation
			A20	Collector's error in milk quality inspection
	E28	Employee workload exceeding standards	A22	Ineffective workload distribution
	E29	Equipment and machinery damage	A14	Milk already physically changed
			A23	Lack of maintenance
			A24	Age factor
	E30	Waste not processed optimally	A15	Tool and machinery damage
			A6	Worker's error in waste processing
	E31	Uncertainty in occupational health and safety during production	A14	Milk already physically changed
			A25	Not using Personal Protective Equipment (PPE)
	E32	Uncertainty in storage cost	A26	Worker's error in determining inventory quantity
	E33	Milk damage during production process	A15	Tool and machinery damage
			A27	Worker's error during production process
	E34	Low worker quality	A9	Lack of work experience
Transportation	E35	Transportation equipment not meeting standards	A19	Low vehicle engine quality
	E36	Milk damage during transportation	A17	Experiencing strong shaking during transportation
			A18	Workplace accidents
	E37	Uncertainty in occupational health and safety during transportation	A25	Not using Personal Protective Equipment (PPE)
			A28	Worker's error during transportation
Product sales	E38	Low customer satisfaction	A29	Low milk quality and quantity
			A30	Milk already physically changed

3.2 House of Risk Phase 1

The House of Risk (HOR) Phase 1 of this study resulted in a comprehensive mapping of risk events and risk agents in the pasteurized milk supply chain. Through questionnaires completed by stakeholders (farmers, collectors, and processing companies), each risk event was assigned a severity score (S) and each risk agent an occurrence score (O). The relationship between the two was measured by the level of correlation, resulting in an Aggregate Risk Potential (ARP) value for each risk agent.

The results in Table 4 show that some risk agents had significantly higher ARP values than others. These dominant risk agents included untimely delivery of raw materials, poor initial quality control, limited storage facilities, and weak operational environmental management. Only a small number of risk agents contributed to the majority of potential disruptions.

In the dairy industry, the perishable nature and reliance on an integrated cold chain make failures extremely high-impact, despite their infrequency [8]. Disruptions such as cold chain facility failures or processing delays can immediately degrade product quality and safety, trigger economic losses, and undermine consumer confidence.

The prioritization of risk agents in HOR Phase 1 also shows how upstream weaknesses can cascade downstream and amplify disruptions. Suboptimal cattle rearing, for example, not only reduces milk yield but also heightens microbial risks that raise processing costs and challenge regulatory compliance. The ARP results underline the systemic influence of upstream hazards, indicating that strengthening farmer-level practices can generate substantial improvements across the supply chain.

The clustering of high-ARP agents further reflects structural issues requiring coordinated action rather than isolated fixes. Limited storage capacity or weak initial quality control often stem from inadequate infrastructure, inconsistent standards, and limited training across actors. These findings emphasize the need for shared governance, harmonized quality protocols, and joint monitoring to ensure that mitigation becomes both technically effective and institutionally sustainable.

The difference in risk structure between the dairy industry and other perishable food commodities (fruits, vegetables, meat) lies in the frequency and impact of events. Sectors other than dairy typically face more frequent disruptions due to seasonal variability and supply chain fragmentation, but the severity of each event is relatively lower due to the diversification of distribution channels [9]. Risk severity tends to be higher in the dairy supply chain due to the critical nature of the cold chain and the integration of the production process, although the frequency of disruptions may be lower [9].

Risk mitigation focuses on risk agents with the highest ARP to make mitigation more effective and efficient by concentrating resources on these "vital few" risks. The focus of risk mitigation in this study was on the two risk agents with the highest ARP, i.e. farmer's error in cattle rearing (A1) and low milk quality and quantity (A12). These risk agents were also identified in previous studies as dominant factors threatening the sustainability of the dairy supply chain [10]. Weaknesses in quality control can trigger contamination incidents or product recalls, while poor environmental management can create significant environmental and reputational risks.

The results of the Phase 1 HOR provide a strong foundation for designing risk mitigation strategies for priority risk agents. This focused approach is expected to strengthen supply chain resilience, reduce potential losses, and support the long-term sustainability of the dairy industry.

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Table 4. House of Risk phase 1

risiko	Agen Risiko	*Severity*																													
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	
E1	9	9																													6
E2			9																												5
E3				9																											6
E4					9																										5
E5						9																									5
E6	9																														6
E7							9																								3
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E9									9	3																					5
E10	9										9																				8
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E37																									9			9			6
E38																													3	9	8
Occurrence	7	5	9	4	4	6	9	9	7	7	6	6	5	6	7	3	5	5	3	3	6	3	5	2	8	6	6	5	6	4	
ARP	2646	270	729	216	180	756	243	648	1008	210	864	1728	855	1134	1323	189	675	675	216	351	432	135	360	144	864	270	432	270	144	288	
Ranking	1	19	10	23	27	9	22	13	5	25	6	2	8	4	3	26	11	12	24	17	14	30	16	28	7	20	15	21	29	18	

3.3 House of Risk Phase 2

The House of Risk (HOR) analysis phase 2 was used to prioritize risk mitigation strategies based on a combination of effectiveness and implementation difficulty. This approach ensures that the selected strategies have a significant impact on risk reduction and are realistic for operational implementation across a pasteurized milk supply chain in Indonesia.

Table 5 shows the draft risk mitigation strategies focused on two priority risk agents resulting from the HOR phase 1. The first risk agent (A1) is farmer's error in cattle rearing, with the highest Aggregate Risk Potential (ARP) of 2646. The mitigation strategies developed for this agent include education on cattle rearing management (PA1), development of Standard Operating Procedures (SOPs) on the farm (PA2), and monitoring of on-farm activities (PA3). The second risk agent (A12) is low milk quality and quantity, with an ARP of 1728, which is mitigated through on-farm activity scheduling (PA4) and business record-keeping (PA5) [4].

Table 5. Plan of risk mitigations

Risk Agent Code	Risk Agent	ARP	Risk Mitigation Code	Risk Mitigation
A1	Farmer's error in cattle rearing	2646	PA1	Education on cattle rearing management
			PA2	Development of SOPs on farms
			PA3	Monitoring of on-farm activities
A12	Low milk quality and quantity	1728	PA4	On-farm activity scheduling
			PA5	Business record-keeping

Education on cattle rearing management (PA1) is aimed at improving farmer capacity through training covering feed management, animal health, sanitation, and hygienic milking procedures [10]. This aligns with the concept of Enhanced Supplier Risk Management. Improving supplier competency upstream in the supply chain is key to reduce the risk of milk quality decline [9].

The development of SOPs on farms (PA2) aims to reduce quality variation and the risk of contamination by ensuring that each process stage has documented operational standards [11]. This strategy aligns with Advanced Quality and Safety Control Measures, which emphasize the importance of implementing standard protocols to maintain food safety.

Monitoring on-farm activities (PA3) plays a role in ensuring compliance with SOPs and detecting potential deviations early. This strategy supports Collaborative Strategies and Stakeholder Integration, which emphasizes the involvement of internal and external parties, such as cooperatives and relevant agencies, in maintaining the quality of raw materials.

Scheduling on-farm activities (PA4) includes planning milking, feeding, livestock health checks, and milk distribution. A structured schedule has been shown to reduce livestock stress and maintain milk quality. This also aligns with the principles of Inventory and Logistics Optimization [9].

Business record-keeping (PA5) forms the basis for the Integration of Digital Tools and Dynamic Decision Support Systems, enabling performance evaluation, quality tracking, and traceability. While its implementation has the potential to increase workload and is hampered by technological limitations, good record-keeping facilitates data-driven decision-making and increases consumer trust.

Table 6 shows the results of the effectiveness to difficulty ratio (ETD_k) calculations for each strategy in HOR phase 2. PA1, PA2, and PA3 received the highest and equal ETD_k scores, thus receiving first priority. The similarity in ETD_k scores for the top three strategies reflects their equivalent mitigation impact and relatively low implementation difficulty, making them feasible to implement in parallel.

Table 6. House of Risk phase 2

Risk Agent	Mitigation Strategies					ARP
	PA1	PA2	PA3	PA4	PA5	
A1	9	9	9			2646
A12				9	9	1728
TE_k	23814	23814	23814	15552	15552	
D_k	4	4	4	3	4	
ETD_k	5954	5954	5954	5184	3888	
Rank	1	1	1	2	3	

Education on cattle rearing management, development of SOPs on farms, and monitoring of on-farm activities should be the initial focus because they have a significant impact on reducing critical risks and can be implemented with minimal obstacles. Once these three strategies are effective, on-farm activity scheduling optimization can be implemented to improve operational efficiency, and then strengthen business record-keeping to support long-term traceability. This phased approach ensures that mitigation strategies are not only technically effective but also appropriate to the available resource capacity, thus supporting the sustainability and resilience of the pasteurized milk supply chain [9].

3.4 Potential Implementation

Education on cattle rearing management, development of SOPs on farms, and monitoring of on-farm activities are prioritized because they target upstream risk sources that have a significant ripple effect on the quality, cost, and performance of the pasteurized milk supply chain [9], [12]. This initial step forms a crucial foundation for a sustainable pasteurized milk supply chain because it ensures a continuous supply of high-quality raw materials, minimizes waste, and maintains competitiveness amid market fluctuations.

Focusing on the upstream is crucial because disruptions at the farm level can impact the quality and continuity of raw material supply. Previous research shows that risks emerging early in the supply chain often spread to subsequent stages and degrade overall performance if not promptly addressed [12]. Upstream risk management also contributes to the environmental dimension by reducing culled milk waste. Improved farmer welfare and more stable partnerships contribute to the social dimension.

Initially, companies need to strengthen education on cattle rearing management, develop SOPs on farms, and monitor daily on-farm activities to ensure effective implementation. These three measures are relatively easy to implement, require moderate costs, and directly address the root causes of quality variation. Challenges typically arise from funding, technological readiness, and analytical capabilities in the field. Practical training modules, simple measuring tools, and direct mentoring can help overcome these obstacles. Collaboration between farmers, collectors, and pasteurized milk companies will accelerate information flow, improve compliance, and reduce downstream risks [12]. This synergy strengthens social sustainability by fostering mutual trust and the active involvement of all supply chain actors.

Regulatory certainty is crucial for the smooth implementation of the first wave strategy. Clear regulations foster business confidence, while appropriate incentives motivate continued practices in the field. Research and innovation support helps accelerate the adoption of technical standards and monitoring tools, while an efficient legal system ensures contract certainty and timely implementation. A strong risk management culture within the organization also plays a significant role in maintaining disciplined strategy implementation.

The second phase focuses on establishing operational schedules on farms. Good scheduling can balance workloads, reduce process variation, and improve resource utilization. More stable processes maintain raw material quality and facilitate coordination between upstream and downstream. This step supports environmental sustainability through energy and transportation efficiency and strengthens economic sustainability by reducing costs associated with inefficient processes. This approach aligns with best practices for data-driven risk mitigation in the dairy supply chain, especially when implemented as a collaborative project between managers and local authorities [9].

The final phase leads to the implementation of integrated business record-keeping. This system provides a critical foundation for tracking, quality audits, and organizational learning. Appropriate quality management standards and certification will link operational controls to sustainability targets [13]. A multi-criteria approach can help evaluate mitigation options in a balanced manner across economic, environmental, and social dimensions. Integrating circular economy principles can also improve resource efficiency and reduce waste.

Access to funding and market conditions are factors that must be managed wisely at all stages. Phased financing schemes, quality-incentive contracts, and flexible access to capital can help overcome cost barriers. Unstable market conditions often create time and cost constraints, while limited liquidity can delay investment in risk management infrastructure [14].

A collaborative approach to governance will accelerate strategy adoption at every stage [14], [15]. Early stakeholder engagement will enhance technical and social buy-in. Cross-sector forums involving policymakers and industry stakeholders can bridge differing needs, while local planning involving communities will strengthen shared awareness and commitment.

The effective risk mitigation strategy in this study begins with upstream strengthening through high-priority actions, continues with operational process structuring, and concludes with an integrated record-keeping system. This approach aligns with the goals of a sustainable pasteurized milk supply chain because it balances rapid risk reduction with efficient resource utilization, maintaining environmental sustainability, strengthening economic stability, and enhancing social value for all stakeholders [9], [12].

4 Conclusion and recommendation

The research results show that the integrated application of the House of Risk (HOR) method to the pasteurized milk supply chain is able to identify and prioritize the risk agents most impacting the system's sustainability. Two primary risk agents—farmer errors in dairy cattle care and low milk quality and quantity—are the focus of strategic interventions because they have the potential to trigger a chain of disruptions across the economic, social, and environmental dimensions. The designed mitigation strategy, which includes education on cattle rearing management, the development of standard operating procedures (SOPs) at the farm level, field activity monitoring, activity scheduling, and business record keeping, can reduce upstream risk sources, maintain raw material quality, and improve operational efficiency. The phased approach, starting from strengthening farmer capacity to implementing an integrated record-keeping system, ensures effective, realistic, and resource-based risk management, thereby increasing the resilience and competitiveness of the pasteurized milk supply chain.

The implementation of this mitigation strategy is expected to not only reduce potential losses and waste but also strengthen partnerships among supply chain actors and ensure long-term business sustainability. Successful implementation depends heavily on crossstakeholder collaboration, clear regulatory support, appropriate incentives, and the availability of training facilities and supporting technology.

Further research is recommended to test the effectiveness of mitigation strategies on a broader industry scale and in dynamic market conditions, including the integration of digital technologies for real-time monitoring and predictive analytics. A multi-criteria approach that combines economic, environmental, and social aspects needs to be further developed to ensure that risk management aligns with sustainability principles and provides added value for all stakeholders.

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