



Mitigating Food Loss and Supply Chain Risks in Red Chili Distribution Using the SCOR-Based House of Risk Approach: A Case Study from Indonesia

Syarifah Akmal*, Yusran Lingga, Syamsul Bahri, Subhan, Anwar

Department of Industrial Engineering, Faculty of Engineering, Universitas Malikussaleh, Aceh, Indonesia

*Correspondence: syarifah.akmal@unimal.ac.id

SUBMITTED: 6 August 2026; REVISED: 25 September 2026; ACCEPTED: 28 September 2026

ABSTRACT: Red chili was a strategic horticultural commodity whose distribution process was highly exposed to supply chain risks that could reduce product quality, disrupt delivery performance, and increase operational costs. This study aimed to identify supply chain risk events and risk agents, determine the dominant sources of risk, and prioritize mitigation strategies for the red chili distribution route from Sidikalang to Medan Central Market using the House of Risk (HOR) method. Supply chain activities were first mapped based on the Supply Chain Operations Reference (SCOR) model, while primary data were collected through interviews and questionnaires involving selected distributors using purposive sampling. House of Risk Phase 1 was applied to evaluate the Aggregate Risk Potential (ARP), followed by House of Risk Phase 2 to determine mitigation priorities using Total Effectiveness (TE) and the Effectiveness-to-Difficulty Ratio (ETD). The results identified 14 risk events and 17 risk agents distributed across the Plan, Source, Deliver, and Return processes. Pareto analysis showed that 11 dominant risk agents accounted for 81.77% of the total ARP value (10,724), with the most critical risks arising from poor road conditions along the Sidikalang–Medan route, adverse weather conditions, and market price fluctuations. Nine preventive actions were proposed, with the preparation of alternative departure schedules combined with continuous monitoring of weather and road conditions identified as the highest-priority mitigation strategy based on the highest ETD value. These findings demonstrated that the integration of the SCOR model and House of Risk provided a systematic approach to identifying priority risks and developing practical mitigation strategies to improve the reliability and resilience of red chili supply chain distribution.

KEYWORDS: House of risk; red chili; risk mitigation; SCOR; supply chain.

1. Introduction

Red chili (*Capsicum annuum* L.) was one of Indonesia's most important horticultural commodities because of its high economic value, strategic role in meeting food demand, and significant contribution to farmers' income. However, its distribution was characterized by considerable price volatility and the involvement of multiple intermediaries throughout the supply chain. Previous studies reported that long distribution chains and the weak bargaining

position of farmers reduced the proportion of profits received by producers [1], while governance structures and limited market integration among value-chain actors were shown to influence both the magnitude of and actors' perceptions of price volatility along Indonesian chili value chains [2, 3]. These conditions indicated that effective supply chain management was essential for maintaining product quality, improving distribution efficiency, reducing postharvest losses, and supporting market stability.

A supply chain comprised a series of interconnected activities involving the flow of products, information, and financial resources from suppliers to end consumers [4]. Nevertheless, agricultural supply chains remained highly vulnerable to various uncertainties because agricultural products were perishable and strongly influenced by environmental conditions, transportation performance, market dynamics, and coordination among supply chain actors [5, 6]. Postharvest studies further demonstrated that infrastructure- and transportation-related factors, including poor road conditions, delays, and inadequate handling, were among the most consistent drivers of quality deterioration, product loss, and economic damage in vegetable supply chains [7]. Consequently, disruptions occurring at any stage of the supply chain could accelerate product deterioration, increase postharvest losses and operational costs, and ultimately reduce the competitiveness and sustainability of agricultural commodities [8, 9]. For highly perishable commodities such as red chili, effective management of distribution risks was therefore particularly important for minimizing avoidable product losses before the commodity reached consumers.

Dairi Regency was one of the major red chili production centers in North Sumatra Province. According to the Central Bureau of Statistics of Dairi Regency, red chili production reached 100,410 quintals in 2022 [10], reflecting the strategic role of this commodity within the region's horticultural sector [11]. A considerable proportion of this production was distributed to Medan City, one of the largest consumption and trading centers in the province. The distribution process involved several supply chain actors, including farmers, collectors who also functioned as distributors, wholesalers at Medan Central Market, retailers, and final consumers. The involvement of multiple actors created numerous interaction points at which operational, transportation, market, and product-quality risks could emerge as red chili moved from the production area to the destination market.

Preliminary interviews with one of the distributors revealed that approximately two tons of red chili were transported from Sidikalang to Medan Central Market in each shipment, with deliveries conducted twice a week and travel times ranging from six to seven hours. Although distribution activities were routinely performed, several operational problems were frequently encountered, including delivery delays, product deterioration during transportation, vehicle breakdowns, and price fluctuations. Similar transportation-related disruptions, including road damage, traffic congestion, and unpredictable delivery times, were documented as major sources of logistics inefficiency in other Indonesian freight corridors [12]. For a highly perishable commodity, such disruptions could not only increase transportation costs and interfere with delivery schedules but also accelerate deterioration and increase the proportion of products that lost marketable quality. These risks could consequently reduce the income of supply chain actors, particularly farmers and distributors, while contributing to avoidable postharvest losses. Therefore, systematic risk management was required to identify the underlying sources of these risks and develop appropriate preventive and mitigation strategies [13].

Supply chain risk management represented an important approach for identifying, assessing, and controlling uncertainties throughout supply chain activities [14]. Effective risk management enabled organizations to reduce operational disruptions while improving supply chain resilience and sustainability, particularly in response to climate- and market-related shocks [6]. In this context, the House of Risk (HOR) method, first proposed in [15], was widely adopted because it integrated the principles of Failure Mode and Effect Analysis (FMEA) and House of Quality (HOQ) [16] to identify risk events, determine their underlying risk agents, prioritize critical sources of risk, and formulate effective mitigation strategies. Furthermore, the Supply Chain Operations Reference (SCOR) model provided a systematic framework for mapping supply chain activities and identifying potential risk points throughout operational processes [17]. The integration of SCOR and HOR therefore provided a comprehensive approach for analyzing supply chain risks and designing targeted preventive actions that could improve distribution reliability and reduce potential product losses.

Previous studies demonstrated the effectiveness of the House of Risk method across various industrial and agricultural sectors, including the pulp industry [13], edamame agroindustry [18], cement bagging operations [19], crumb rubber manufacturing [20], a banana supply chain in Peru [21], and small and medium-sized food enterprises in Indonesia [22, 23]. Other studies employed the SCOR model, either independently or in combination with HOR, to evaluate supply chain performance and risks associated with retail products [24] and regional agro-industrial products [25]. Studies of perishable-food supply chains also highlighted dairy and vegetable products as being particularly vulnerable to transportation- and cold-chain-related risks [9, 26]. In contrast, studies on red chili in Indonesia primarily focused on supply chain efficiency, price behavior, and marketing performance rather than systematic risk identification and mitigation [1–3]. Moreover, limited attention was given to how distribution-related risks could contribute to quality deterioration and postharvest losses in red chili supply chains. Thus, a research gap remained in systematically identifying critical risk agents and prioritizing preventive strategies for red chili distribution along the Sidikalang–Medan route through the integrated application of SCOR and HOR. Addressing this gap was important for supporting a more resilient distribution system while minimizing avoidable losses of a highly perishable horticultural commodity.

Therefore, this study aimed to analyze supply chain risks in the distribution of red chili from Sidikalang to Medan Central Market by employing the Supply Chain Operations Reference (SCOR) model to map supply chain activities and the House of Risk (HOR) method to identify risk events, determine priority risk agents, and formulate mitigation strategies. Specifically, the study sought to identify critical operational and distribution risks that could contribute to delivery disruptions, quality deterioration, and postharvest losses and to prioritize preventive actions based on their effectiveness and implementation difficulty. The findings were expected to provide practical recommendations for supply chain stakeholders to minimize distribution risks and potential product losses while contributing to the development of more resilient and sustainable risk-management practices for horticultural supply chains in Indonesia.

2. Materials and Methods

2.1. Study Area and Research Design.

This study employed a descriptive quantitative design supported by qualitative data collection. The qualitative component was conducted during the initial stage to characterize supply chain activities and identify risk events, risk agents, and potential mitigation measures through direct observation and in-depth interviews with selected respondents. Subsequently, quantitative analysis was performed using the House of Risk (HOR) method to calculate the Aggregate Risk Potential (ARP), Total Effectiveness (TE), and Effectiveness-to-Difficulty Ratio (ETD), which were used to prioritize supply chain risks and determine appropriate mitigation strategies. The study was conducted along the red chili distribution route connecting Sidikalang, Dairi Regency, North Sumatra, as the production area, with Medan City as the principal destination market. Sidikalang represented one of the major red chili production centers in North Sumatra and contributed to regional market supply. The analysis focused on supply chain activities involving farmers, collectors/distributors, wholesalers, retailers, and final consumers along the Sidikalang–Medan distribution route. The supply chain structure examined in this study is presented in Figure 1.

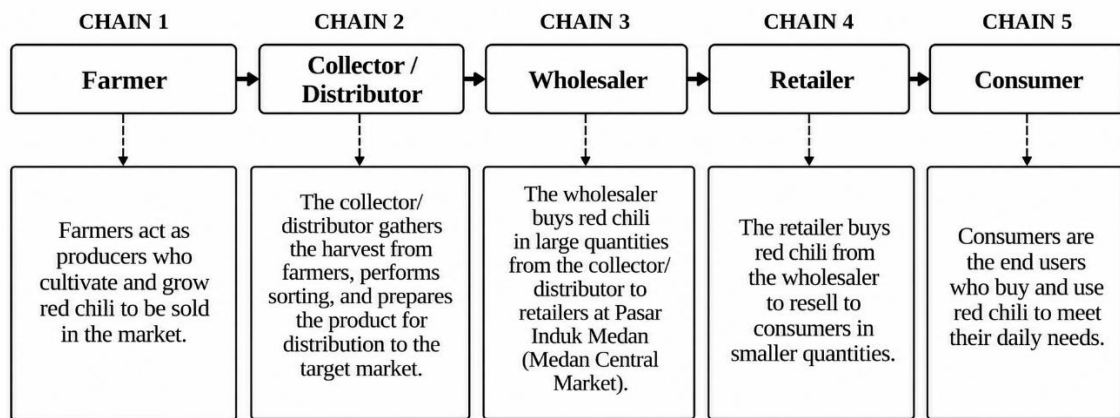


Figure 1. Supply chain structure of the red chili distribution system from Sidikalang to Medan.

2.2. Data Collection.

Both primary and secondary data were collected. Primary data were obtained through field observations, in-depth interviews, and structured questionnaires administered to selected respondents. Direct observations were conducted to characterize the movement of products and the associated flows of information and financial transactions throughout the supply chain. In-depth interviews were subsequently conducted to identify supply chain activities, potential risk events, their underlying risk agents, and feasible preventive actions. Structured questionnaires were used to obtain respondents' assessments of the severity of each risk event, the occurrence of each risk agent, the relationships between risk events and risk agents, and the implementation difficulty associated with the proposed preventive actions in HOR Phase 2. Secondary data were obtained from scientific publications, books, government reports, statistical publications, and other relevant documents concerning red chili production, agricultural supply chain management, the SCOR framework, and the HOR methodology.

2.3. Respondent Selection.

Respondents were selected using purposive expert sampling based on their direct involvement, relevant knowledge, and practical experience in the red chili distribution system. This approach was considered appropriate because the HOR assessment required informed judgments from individuals with substantial operational knowledge rather than statistical representation of the general population [27, 28]. Respondents were required to meet three criteria: (1) active involvement in the Sidikalang–Medan red chili supply chain; (2) at least five years of professional experience in red chili production or distribution; and (3) willingness to participate in the interviews and complete the research questionnaires. Data collection was conducted iteratively. The initial assessment involved three respondents who identified relevant risk events and risk agents and provided preliminary severity and occurrence scores. Two additional respondents who met the same eligibility criteria were subsequently included to examine the consistency of these assessments, resulting in a final expert panel of five collectors/distributors. The consistency of respondents' judgments was evaluated using the standard deviation (SD) of individual scores, as described in Section 2.4.

All five respondents were collectors/distributors. This respondent group was deliberately selected because collectors/distributors occupied a central operational position within the Sidikalang–Medan supply chain. Their activities extended from the collection and sorting of red chili at the production level to transportation and delivery to the wholesale market in Medan, providing direct knowledge of risks occurring across the distribution segment. Furthermore, because the study specifically focused on risks associated with the Sidikalang–Medan transportation and distribution route, collectors/distributors represented the most information-rich participants for the defined study scope. The use of a relatively small and homogeneous panel of experienced respondents was consistent with purposive expert-sampling approaches, in which the relevance and consistency of expert judgment are emphasized rather than statistical representativeness across the entire supply chain [27, 28]. Nevertheless, reliance exclusively on collectors/distributors constituted a methodological limitation. Risk perceptions specific to farmers, including production and pre-harvest risks, and those specific to wholesalers and retailers, including downstream demand and retail-level risks, were not directly captured. Therefore, the findings primarily represented distribution-related risks from the perspective of collectors/distributors and should be interpreted within this defined scope.

2.4. Research Procedure and House of Risk Analysis.

The research was conducted through a series of sequential stages based on the House of Risk framework [15]. First, supply chain activities were mapped using the Supply Chain Operations Reference (SCOR) framework [17]. The analysis covered the Plan, Source, Deliver, and Return processes relevant to the investigated distribution system. This mapping provided the operational basis for systematically identifying potential risk events throughout the supply chain. Second, risk events (E_i) and risk agents (A_j) were identified through field observations and in-depth interviews with the selected respondents. The severity (S_i) of each risk event was independently assessed by each respondent using a structured questionnaire with a 1–10 ordinal scale, where higher scores represented greater potential impacts on distribution performance.

The final severity score used in the HOR calculations was obtained by calculating the arithmetic mean of the individual respondent scores.

Similarly, the occurrence score (O_j) of each risk agent was assessed using a 1–10 ordinal scale and averaged across respondents, with higher scores indicating a greater perceived frequency of occurrence. The relationship (R_{ij}) between each risk agent and risk event was determined through group discussion until a consensus value was reached. Relationships were evaluated using the standard HOR scale of 0, 1, 3, and 9, corresponding to no, low, moderate, and strong relationships, respectively [15]. To evaluate the consistency of the severity and occurrence assessments and support the use of mean scores in the HOR calculations, the standard deviation (SD) of respondents' individual scores was calculated using Equation (1):

$$SD = \sqrt{[\sum(x_i - \bar{x})^2 / (n - 1)]} \quad (1)$$

where x_i represented the score provided by respondent i , $\bar{x}$ represented the mean score across respondents, and n represented the number of respondents. Lower SD values indicated greater agreement among respondents. Across the 14 identified risk events, SD values ranged from 0.75 to 1.79, indicating relatively limited dispersion in respondents' assessments and supporting the use of mean scores as summary measures of the expert panel's judgments.

Third, House of Risk Phase 1 (HOR Phase 1) was applied to calculate the Aggregate Risk Potential (ARP) for each risk agent using Equation (2) [15]:

$$ARP_j = O_j \times \sum_i(S_i \times R_{ij}) \quad (2)$$

where ARP_j is the aggregate risk potential of risk agent j , O_j is the occurrence score of risk agent j , S_i is the severity score of risk event i , and R_{ij} is the relationship value between risk agent j and risk event i . Risk agents were then ranked by ARP value, and Pareto analysis was applied to identify the priority risk agents requiring immediate mitigation, following the 80/20 principle commonly used in quality and risk-prioritization studies [16].

Finally, House of Risk Phase 2 (HOR Phase 2) was conducted to develop preventive actions (PA_k) for the selected priority risk agents. The relationship between each preventive action and each risk agent was assessed using a correlation value (E_{jk}) on the same 0–1–3–9 scale, and the Total Effectiveness (TE_k) of each preventive action was calculated using Equation (3):

$$TE_k = \sum_j(ARP_j \times E_{jk}) \quad (3)$$

The implementation difficulty (D_k) of each preventive action was assessed by respondents on an ordinal scale of 3 (low), 4 (moderate), and 5 (high), reflecting the required resources, cost, and implementation complexity. The Effectiveness-to-Difficulty Ratio (ETD_k), used to determine the final mitigation priority, was then calculated using Equation (4):

$$ETD_k = TE_k / D_k \quad (4)$$

Preventive actions were ranked by ETD_k value, with the highest-ranked action representing the most optimal mitigation strategy in terms of effectiveness relative to implementation difficulty. The complete sequence of these stages is summarized in Figure 2.

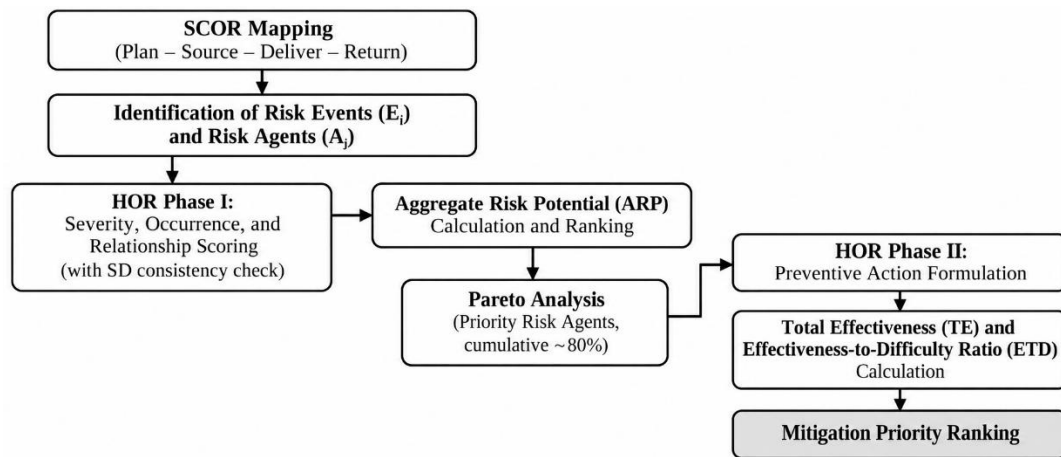


Figure 2. Methodological Flowchart of the Research Process, from SCOR Mapping to Mitigation Priority Ranking.

2.5. Data Analysis.

The collected data were analyzed using an integrated SCOR–HOR framework. SCOR mapping was initially used to structure the distribution activities and establish the operational context for risk identification. HOR Phase 1 was then employed to quantify and rank the identified risk agents based on their ARP values. Pareto analysis was applied to select the priority risk agents for subsequent mitigation analysis. The selected risk agents were further evaluated in HOR Phase 2 to develop and prioritize preventive actions. TE and ETD values were calculated to determine the relative priority of each mitigation strategy by considering both its expected effectiveness and implementation difficulty. Descriptive statistics, including means and standard deviations, were used to summarize respondents' assessments. All quantitative calculations were performed using Microsoft Excel.

2.6. Ethical Considerations.

Participation in the study was voluntary. Before the interviews and questionnaire surveys were conducted, all respondents were informed of the study objectives and agreed to participate. Respondents' identities were kept confidential, and the information obtained during data collection was used exclusively for research purposes.

3. Results and Discussion

3.1. Supply Chain Mapping and Risk Identification.

The red chili supply chain consisted of five primary actors: farmers, collectors/distributors, wholesalers at Medan Central Market, retailers, and consumers. Collectors/distributors played a central role by consolidating red chili from multiple farmers, performing preliminary sorting and packaging, organizing transportation, and delivering the products to wholesalers. Therefore, their activities directly influenced product quality, delivery timeliness, and supply continuity. Based on the Supply Chain Operations Reference (SCOR) model, the distribution activities were classified into four core processes: Plan, Source, Deliver, and Return. As summarized in Table 1, these processes covered activities from shipment planning and product collection to transportation and the handling of rejected products. This classification provided the operational basis for systematically identifying potential risks along the distribution chain.

Table 1. SCOR-Based Supply Chain Activities of the Red Chili Distribution Process.

Process	Activities
Plan	Planning shipment quantity; planning delivery schedule
Source	Collecting red chili from farmers; sorting and packaging
Deliver	Loading products into transportation vehicles; delivering products to Medan Central Market; unloading products
Return	Handling rejected products

Risk identification based on these activities resulted in 14 risk events, as presented in Table 2. The Deliver process contained the largest number of risk events, particularly those related to transportation delays, handling damage, product deterioration, and increased distribution costs. This concentration indicated that transportation represented a critical stage for maintaining the quality and marketability of fresh red chili.

Table 2. Identified Risk Events in the Red Chili Supply Chain.

Code	Process	Risk event
E1	Plan	Incorrect estimation of shipment quantity
E2	Plan	Delay in shipment departure
E3	Source	Delay in collecting products from farmers
E4	Source	Inconsistent product quality
E5	Source	Product damage during sorting
E6	Source	Improper packaging causing product damage
E7	Deliver	Product damage during loading
E8	Deliver	Transportation delay
E9	Deliver	Product deterioration during transportation
E10	Deliver	Increased distribution costs during transportation
E11	Deliver	Product damage during unloading
E12	Deliver	Delay in unloading due to congestion at Medan Central Market
E13	Return	Product rejection by buyers
E14	Return	Financial losses caused by rejected products

The identified risk events occurred throughout the distribution process rather than at a single stage. Risks associated with the Return process were also important because quality deterioration during earlier stages could ultimately lead to buyer rejection and financial losses. Thus, distribution failures could have cumulative effects extending from operational disruption to economic loss. The underlying causes of these events were subsequently identified as 17 risk agents, as summarized in Table 3. These agents represented internal operational weaknesses and external factors related to infrastructure, weather, traffic, and market conditions. Transportation-related factors constituted a substantial source of potential disruption. Poor road conditions, adverse weather, traffic congestion, prolonged transportation without cold-chain facilities, and vehicle breakdowns could collectively increase the likelihood of physical damage, deterioration, delivery delays, and additional logistics costs. Internal risks, such as inappropriate packaging and handling, could potentially be addressed through operational improvements, whereas external risks required more adaptive mitigation strategies. The identified risk events and agents were subsequently evaluated using HOR Phase I to determine which risk sources should receive priority attention.

Table 3. Identified Risk Agents in the Red Chili Supply Chain.

Code	Risk agent
A1	Limited market demand information
A2	Lack of structured shipment planning
A3	Unpredictable harvesting schedules
A4	Scattered farmer locations
A5	Absence of consistent grading standards
A6	Improper manual handling during sorting
A7	Inappropriate packaging
A8	Manual loading without standard procedures
A9	Vehicle breakdowns
A10	Poor road conditions along the Sidikalang–Medan route
A11	Adverse weather conditions
A12	Traffic congestion
A13	Long transportation duration without cold-chain facilities
A14	Improper unloading practices
A15	Long unloading queues at Medan Central Market
A16	Absence of standardized product acceptance criteria
A17	Market price fluctuations

3.2. Risk Assessment Using House of Risk Phase I.

HOR Phase I integrated the severity of each risk event, the occurrence of each risk agent, and their interrelationships to calculate the Aggregate Risk Potential (ARP). Severity represented the consequences of a risk event, whereas occurrence represented the likelihood of a risk agent arising during distribution. The mean assessment scores are presented in Table 4.

Table 4. Severity and Occurrence Assessment Results.

Code	Risk Event	Severity	Code	Risk Agent	Occurrence
E1	Incorrect estimation of red chili shipment quantity	5	A1	Insufficient information regarding market conditions and demand in Medan	5
E2	Delay in departure from the scheduled time	7	A2	Lack of a structured shipment planning and recording system	4
E3	Delay in collecting red chili from farmers	5	A3	Uncertain and unpredictable harvesting schedules	8
E4	Inconsistent quality of received red chili	3	A4	Farmers are geographically dispersed, increasing collection time	5
E5	Product damage during sorting	6	A5	Inconsistent implementation of grading standards by farmers	8
E6	Improper packaging causing product damage	5	A6	Manual and careless sorting practices	5
E7	Product damage during loading	7	A7	Inappropriate packaging (overfilled or poorly ventilated)	4
E8	Delay in delivery to destination	7	A8	Manual loading without standardized procedures	5
E9	Product damage during transportation	8	A9	Vehicle breakdown or mechanical failure	7
E10	Increased distribution costs due to transportation disruptions	6	A10	Poor road conditions along the Sidikalang–Medan route	9
E11	Product damage during unloading	6	A11	Adverse weather conditions	9
E12	Delay in unloading due to congestion at Medan Central Market	6	A12	Traffic congestion on the route to Medan	8
E13	Product rejection by buyers	8	A13	Long transportation time (6–7 hours) without cold chain facilities	6
E14	Financial losses caused by rejected products	9	A14	Improper unloading practices at Medan Central Market	5
—	—	—	A15	Long queue at the unloading area of Medan Central Market	7
—	—	—	A16	Absence of standardized product acceptance criteria between distributors and buyers	4
—	—	—	A17	Market price fluctuations leading to product rejection	7

Financial losses caused by rejected products (E14) had the highest severity score (9), followed by product rejection (E13) and product deterioration during transportation (E9), both with scores of 8. These results indicated that downstream quality failures had particularly serious economic consequences. In terms of occurrence, poor road conditions (A10) and adverse weather (A11) received the highest scores (9), followed by uncertain harvesting schedules (A3), inconsistent grading standards (A5), and traffic congestion (A12), each with a score of 8.

The interactions between risk agents and risk events were then evaluated using relationship scores of 0, 1, 3, and 9, representing no, low, moderate, and strong relationships, respectively. Table 5 presents the resulting relationship matrix used for the ARP calculation. The matrix showed that several risk agents contributed to multiple risk events. Poor road conditions (A10), for example, were strongly associated with transportation delays (E8), product deterioration during transportation (E9), and increased distribution costs (E10). Similarly, adverse weather (A11) was strongly associated with both delivery delays and product deterioration. This pattern explains why transportation-related agents could generate greater cumulative risk than agents associated with only one risk event.

Table 5. Relationship Matrix Between Risk Events and Risk Agents.

Risk Event	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17
E1	9	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E2	3	9	1	9	0	0	0	0	1	0	0	0	0	0	0	0	0
E3	0	1	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	3	1	9	1	0	0	0	0	0	0	0	0	0	0	1
E5	0	0	0	0	3	9	0	0	0	0	0	0	0	0	0	0	0
E6	0	0	0	0	0	1	9	0	0	0	0	0	0	0	0	0	0
E7	0	0	0	0	0	0	1	9	0	0	0	0	0	0	0	0	0
E8	0	0	0	0	0	0	0	0	9	9	9	9	0	0	0	0	0
E9	0	0	0	0	0	0	3	0	1	9	9	1	9	0	0	0	0
E10	0	0	0	0	0	0	1	0	9	9	3	3	0	0	0	0	0
E11	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0
E12	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	0	0
E13	0	0	0	0	3	0	0	0	0	1	1	0	1	1	0	9	9
E14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	9

Based on the severity, occurrence, and relationship scores, ARP values were calculated and ranked to identify the dominant sources of risk. Table 6 presents the complete ranking and cumulative contribution of the 17 risk agents.

Table 6. Aggregate Risk Potential (ARP) Ranking.

Rank	Code	Risk Agent	ARP	Percentage (%)	Cumulative (%)
1	A10	Poor road conditions along the Sidikalang–Medan route	1773	16.53	16.53
2	A11	Adverse weather conditions	1449	13.51	30.04
3	A17	Market price fluctuations leading to product rejection	1092	10.18	40.23
4	A9	Vehicle breakdown or mechanical failure	924	8.62	48.84
5	A12	Traffic congestion on the route to Medan	712	6.64	55.48
6	A3	Uncertain harvesting schedules	608	5.67	61.15
7	A5	Inconsistent grading standards applied by farmers	552	5.15	66.30
8	A13	Long transportation time without cold chain facilities	480	4.48	70.78
9	A4	Farmers are geographically dispersed	405	3.78	74.55
10	A16	Lack of standardized product acceptance criteria	396	3.69	78.25
11	A15	Long unloading queue at Medan Central Market	378	3.52	81.77
12	A14	Improper unloading practices	340	3.17	84.94
13	A2	Lack of structured shipment planning and recording	332	3.10	88.04
14	A1	Insufficient market information	330	3.08	91.11
15	A7	Inappropriate packaging	328	3.06	94.17
16	A8	Manual loading without standardized procedures	315	2.94	97.11
17	A6	Manual and careless sorting practices	310	2.89	100.00

Poor road conditions along the Sidikalang–Medan route (A10) ranked first, with an ARP of 1,773 and a contribution of 16.53%, followed by adverse weather (A11; ARP = 1,449; 13.51%) and market price fluctuations (A17; ARP = 1,092; 10.18%). To clarify the concentration of risk among the highest-ranked agents, the ARP values and their cumulative contribution are visualized in Figure 3.

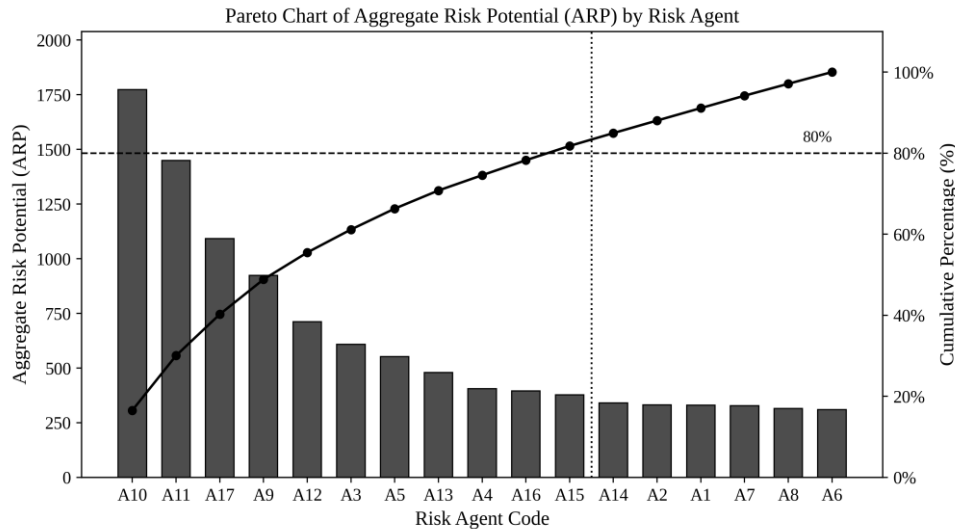


Figure 3. Pareto chart of Aggregate Risk Potential (ARP) by Risk Agent, Showing the Cumulative Contribution of the Eleven Priority Risk Agents ($\approx 81.77\%$).

Poor road conditions emerged as the dominant risk because they simultaneously affected delivery time, product integrity, and transportation costs. The Sidikalang–Medan route includes challenging road sections, while transportation typically requires six to seven hours. Poor rural road infrastructure has similarly been associated with increased agricultural product damage, longer transportation times, and higher distribution costs [29]. The strong relationships of A10 with E8, E9, and E10 in Table 5 therefore explain its high cumulative ARP. Adverse weather (A11) ranked second and was particularly important because red chili was transported without a cold-chain system. Exposure to rainfall, temperature fluctuations, and prolonged transportation can accelerate deterioration in fresh agricultural commodities. This result was consistent with previous studies identifying climate variability and inadequate cold-chain infrastructure as important sources of disruption in perishable agricultural supply chains [6, 9]. Market price fluctuations (A17) ranked third. Although this factor was market-related rather than operational, it was strongly associated with product rejection (E13) and financial loss (E14), which had among the highest severity scores. Limited price coordination before shipment could expose distributors to substantial losses when market prices changed during transportation. Similar price volatility and coordination challenges have been reported in Indonesian chili value chains [2, 3]. As illustrated in Figure 3, the first 11 risk agents accounted for 81.77% of the total ARP. Following the Pareto principle [16], these agents were therefore selected as priorities for HOR Phase II. The remaining six agents were retained as secondary risks because their individual contributions were comparatively lower.

3.3. House of Risk Phase II: Prioritization of Preventive Actions.

HOR Phase II was used to identify feasible preventive actions for the 11 priority risk agents identified in Phase I. Nine preventive actions were developed based on expert judgment and

the operational characteristics of the Sidikalang–Medan distribution system. As shown in Table 7, several actions were designed to address more than one risk agent simultaneously. PA1 targeted both poor road conditions (A10) and adverse weather (A11), while PA4 addressed uncertain harvesting schedules (A3) and geographically dispersed farmers (A4). Such combined actions were potentially more efficient because a single intervention could address several interconnected sources of disruption.

Table 7. Proposed Preventive Actions for Dominant Risk Agents.

Code	Preventive action	Targeted risk agent(s)
PA1	Develop alternative departure schedules and monitor weather and road conditions before shipment	A10, A11
PA2	Perform routine preventive maintenance of transportation vehicles	A9
PA3	Determine alternative transportation routes and departure times to avoid traffic congestion	A12
PA4	Establish regular communication with farmers regarding harvest schedules	A3, A4
PA5	Implement standardized chili grading practices with farmers	A5
PA6	Utilize insulated packaging or simple cooling materials during transportation	A13
PA7	Establish preliminary price agreements with buyers before shipment	A17
PA8	Develop mutually agreed product acceptance standards between distributors and buyers	A16, A17
PA9	Coordinate unloading schedules with the Medan Central Market management	A15

The effectiveness of each preventive action against the priority risk agents was subsequently assessed using the HOR Phase II relationship matrix. Table 8 presents the relationship scores used to calculate the Total Effectiveness (TE) of each preventive action. PA1 had strong relationships with A10 and A11, the two highest-ranked risk agents in Phase I. Consequently, this action had the potential to address a substantial proportion of the overall risk exposure. In contrast, actions such as PA9 targeted a more specific risk agent and therefore produced a lower overall risk-reduction effect.

Table 8. House of Risk Phase II Relationship Matrix.

PA	A10	A11	A17	A9	A12	A3	A5	A13	A4	A16	A15
PA1	9	9	0	0	3	0	0	1	0	0	0
PA2	1	0	0	9	0	0	0	1	0	0	0
PA3	1	0	0	0	9	0	0	1	0	0	0
PA4	0	0	0	0	0	9	1	0	9	0	0
PA5	0	0	3	0	0	0	9	0	1	0	0
PA6	1	1	0	0	0	0	0	9	0	0	0
PA7	0	0	9	0	0	0	0	0	0	3	0
PA8	0	0	3	0	0	0	0	0	0	9	0
PA9	0	0	0	0	1	0	0	0	0	0	9

The TE values were then considered together with implementation difficulty (Dk) to calculate the Effectiveness-to-Difficulty Ratio (ETD). Table 9 presents the resulting priority ranking, where a higher ETD indicated a more favorable balance between mitigation effectiveness and implementation difficulty.

Table 9. Priority Ranking of Preventive Actions Based on ETD Values.

Rank	Code	Preventive action	TE	Dk	ETD
1	PA1	Develop alternative departure schedules and monitor weather and road conditions	31,614	3	10,538
2	PA3	Determine alternative routes and departure times	8,661	3	2,887
3	PA2	Routine preventive maintenance of transportation vehicles	10,569	4	2,642
4	PA4	Establish regular communication with farmers regarding harvest schedules	9,669	4	2,417
5	PA7	Establish preliminary price agreements with buyers	11,016	5	2,203
6	PA6	Utilize insulated packaging or simple cooling materials	7,542	4	1,886
7	PA5	Implement standardized chili grading practices with farmers	8,649	5	1,730
8	PA8	Develop mutually agreed product acceptance standards	6,840	5	1,368
9	PA9	Coordinate unloading schedules with market management	4,114	4	1,029

PA1, which involved developing alternative departure schedules and monitoring weather and road conditions, ranked first with an ETD of 10,538. This value was more than three times that of PA3 (ETD = 2,887), the second-ranked strategy. The substantial difference resulted from PA1 having both the highest Total Effectiveness (TE = 31,614) and relatively low implementation difficulty (Dk = 3). The relative priorities of all nine preventive actions are illustrated in Figure 4.

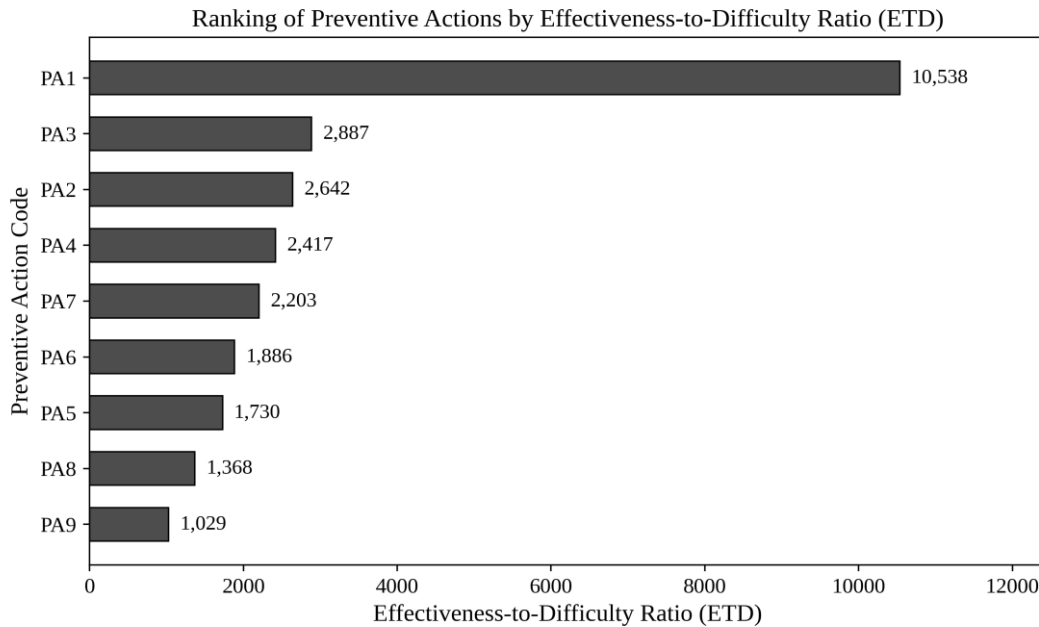


Figure 4. Ranking of preventive actions by Effectiveness-to-Difficulty Ratio (ETD).

From an operational perspective, PA1 could be implemented by checking weather and road conditions before dispatch and allowing limited flexibility in the twice-weekly delivery schedule. Such measures could reduce transportation delays (E8) and product deterioration during transit (E9), which were strongly associated with A10 and A11. However, schedule adjustments would require communication with wholesalers to minimize disruption to expected delivery times. PA3 and PA2 also represented relatively feasible operational measures. Alternative routes and departure times could reduce exposure to traffic congestion, while preventive vehicle maintenance could reduce mechanical failures during transportation. In contrast, PA7, involving preliminary price agreements, depended on cooperation between distributors and buyers. Its implementation could therefore be more difficult in a fragmented supply chain with limited formal contracting, as also reported for Indonesian chili value chains [3]. PA4 and PA5 primarily required improved coordination with farmers, whereas PA6 required modest investment in insulated packaging or simple cooling materials. PA8 and PA9 depended more heavily on cooperation with buyers and market management. These results indicated that mitigation feasibility was influenced not only by technical effectiveness but also by the extent to which implementation remained under the distributor's control. Overall, HOR Phase II showed that operational interventions involving scheduling, route planning, monitoring, and vehicle maintenance offered more favorable short-term effectiveness-to-difficulty ratios than strategies requiring institutional or contractual changes. This finding supports the broader principle that mitigation strategies in resource-constrained agricultural supply chains should consider implementation feasibility alongside expected risk reduction [5]. Therefore, PA1–PA3 could be prioritized for short-term implementation, whereas actions

requiring coordination with farmers, buyers, or market management could be progressively developed as medium-term measures.

4. Conclusions

This study applied the House of Risk (HOR) method integrated with the Supply Chain Operations Reference (SCOR) framework to identify, assess, and prioritize risks in the red chili distribution supply chain along the Sidikalang–Medan route. The analysis identified 14 risk events and 17 risk agents distributed across the planning, sourcing, delivery, and return processes. Pareto analysis showed that 11 dominant risk agents, led by poor road conditions (ARP = 1,773), adverse weather conditions (ARP = 1,449), and market price fluctuations (ARP = 1,092), accounted for approximately 81.77% of the total Aggregate Risk Potential, indicating that external environmental and transportation-related factors contribute most significantly to supply chain disruptions. House of Risk Phase 2 produced nine preventive actions, of which preparing alternative departure schedules while continuously monitoring weather and road conditions (PA1) achieved the highest Effectiveness-to-Difficulty Ratio (ETD = 10,538), making it the top-priority mitigation strategy. Other high-priority actions include adjusting transportation routes and departure times (PA3) and performing routine vehicle maintenance (PA2), both of which are readily implementable using resources already available to distributors. These findings demonstrate that the integration of SCOR and House of Risk provides a systematic, practical framework for prioritizing agricultural supply chain risks under resource constraints. For the Sidikalang–Medan red chili distribution system, low-cost operational improvements, rather than institutional or contractual changes, offer distributors the most immediate and feasible path toward a more resilient and reliable supply chain.

Acknowledgments

The authors would like to express their sincere gratitude to the Department of Industrial Engineering, Faculty of Engineering, Universitas Malikussaleh, for providing academic support throughout this research. The authors also gratefully acknowledge all respondents, including farmers, distributors, and market stakeholders involved in the red chili distribution process between Sidikalang and Medan Central Market, for their valuable time, information, and cooperation during the data collection process. Special appreciation is extended to all individuals who provided constructive suggestions and support that contributed to the completion of this study.

Author Contribution

Conceptualization: Syarifah Akmal; Methodology: Syarifah Akmal, Yusran Lingga, and Syamsul Bahri; Data Collection: Subhan and Anwar; Data Analysis: Syarifah Akmal and Subhan; Writing – Original Draft Preparation: Syarifah Akmal; Writing – Review and Editing: Syarifah Akmal, Yusran Lingga, Syamsul Bahri, Subhan, and Anwar; Supervision: Syarifah Akmal. All authors have read and approved the published version of the manuscript.

Competing Interest

The authors declare that they have no competing interests.

References

- [1] Renaldi, E.; Pardian, P.; Kuswatim, S.H. (2025). Analisis efisiensi struktur rantai pasok agribisnis cabai merah besar di Desa Sindulang, Kabupaten Sumedang. *Jurnal Pertanian Agros*, 27, 346–354. <https://doi.org/10.37159/jpa.v27i3.110>.
- [2] Muflikh, Y.N.; Smith, C.; Brown, C.; Aziz, A.A. (2021). Analysing price volatility in agricultural value chains using systems thinking: A case study of the Indonesian chilli value chain. *Agricultural Systems*, 192, 103179. <https://doi.org/10.1016/j.agsy.2021.103179>.
- [3] Muflikh, Y.N.; Adhikari, R.; Abdul Aziz, A. (2023). Governance structures and price volatility perceptions in the Indonesian chilli value chain. *Journal of Agribusiness in Developing and Emerging Economies*, 13, 631–655. <https://doi.org/10.1108/JADEE-08-2021-0198>.
- [4] Anam, S.; et al. (2025). Analisis sistem rantai pasok modern: Studi literatur terhadap perkembangan terbaru. *Jurnal Penelitian Nusantara*, 1, 210–213. <https://doi.org/10.59435/menulis.v1i7.526>.
- [5] Behzadi, G.; O'Sullivan, M.J.; Olsen, T.L.; Zhang, A. (2018). Agribusiness supply chain risk management: A review of quantitative decision models. *Omega*, 79, 21–42. <https://doi.org/10.1016/j.omega.2017.07.005>.
- [6] Ghadge, A.; Wurtmann, H.; Seuring, S. (2020). Managing climate change risks in global supply chains: A review and research agenda. *International Journal of Production Research*, 58, 44–64. <https://doi.org/10.1080/00207543.2019.1629670>.
- [7] Qange, S.; Mdoda, L.; Mditshwa, A. (2024). Modeling the critical causal factors of postharvest losses in the vegetable supply chain in eThekweni Metropolitan Municipality: The log-linear regression model. *Heliyon*, 10, e39565. <https://doi.org/10.1016/j.heliyon.2024.e39565>.
- [8] Mizani, T.T.; Azis, A.M. (2021). Analisis kerangka kerja, aliran, dan hambatan rantai pasokan. *Jurnal Manajemen Maranatha*, 21, 17–24. <https://doi.org/10.28932/jmm.v21i1.4040>.
- [9] Khalid, R.U.; Jajja, M.S.S.; Ahsan, M.B. (2024). Supply chain sustainability and risk management in food cold chains – A literature review. *Modern Supply Chain Research and Applications*, 6, 193–221. <https://doi.org/10.1108/MS CRA-07-2023-0030>.
- [10] Badan Pusat Statistik Kabupaten Dairi. (2023). Statistik Hortikultura Kabupaten Dairi Tahun 2022; Badan Pusat Statistik Kabupaten Dairi: Sidikalang, Indonesia.
- [11] Direktorat Jenderal Hortikultura. (2024). Profil Hortikultura Indonesia; Kementerian Pertanian Republik Indonesia: Jakarta, Indonesia.
- [12] Soimun, A.; Sadri, P.D.A.; Navianti, D.R.; Fitri, S.N. (2025). The impact of traffic congestion on freight transport efficiency in a tourism corridor: A case study of the Denpasar–Gilimanuk road. *Journal of Applied Sciences in Travel and Hospitality*, 8, 177–198. <https://doi.org/10.31940/jasth.v8i2.177-198>.
- [13] Purwaningsih, R.; Ibrahim, C.N.; Susanto, N. (2021). Analisis dan mitigasi risiko supply chain pada pengadaan material produksi dengan model House of Risk (HOR) pada PT. Toba Pulp Lestari Tbk, Porsea, Sumatra Utara. *MIX: Jurnal Ilmiah Manajemen*, 11, 64. <https://doi.org/10.22441/mix.2021.v11i1.005>.

- [14] Heckmann, I.; Comes, T.; Nickel, S. (2015). A critical review on supply chain risk – Definition, measure and modeling. *Omega*, 52, 119–132. <https://doi.org/10.1016/j.omega.2014.10.004>.
- [15] Pujawan, I.N.; Geraldin, L.H. (2009). House of risk: A model for proactive supply chain risk management. *Business Process Management Journal*, 15, 953–967. <https://doi.org/10.1108/14637150911003801>.
- [16] Stamatis, D.H. (2003). Failure Mode and Effect Analysis: FMEA from Theory to Execution, 2nd ed.; ASQ Quality Press: Milwaukee, WI, USA.
- [17] Huan, S.H.; Sheoran, S.K.; Wang, G. (2004). A review and analysis of supply chain operations reference (SCOR) model. *Supply Chain Management: An International Journal*, 9, 23–29. <https://doi.org/10.1108/13598540410517557>.
- [18] Prasetyo, D.S.; Emaputra, A.; Parwati, C.I. (2021). Pengukuran kinerja supply chain management menggunakan pendekatan model Supply Chain Operations Reference (SCOR) pada IKM Kerupuk Subur. *Jurnal PASTI*, 15, 80. <https://doi.org/10.22441/pasti.2021.v15i1.008>.
- [19] Sayuti, M.; Fatimah, F.; Sahara, S. (2022). Analisis manajemen resiko pada unit pengantongan Semen Padang dengan pendekatan House of Risk. *Industrial Engineering Journal*, 11. <https://doi.org/10.53912/iej.v11i2.947>.
- [20] Immawan, T.; Putri, D.K. (2018). House of risk approach for assessing supply chain risk management strategies: A case study in Crumb Rubber Company Ltd. *MATEC Web of Conferences*, 154, 01097. <https://doi.org/10.1051/mateconf/201815401097>.
- [21] Avila-Arteaga, C.; Arauco-Galarza, G.; Ramos, E.; Shinno-Huamani, M. (2021). Supply chain management based on house of risk: A case study in a Peruvian banana company. pp. 513–519. https://doi.org/10.1007/978-3-030-55307-4_78.
- [22] Ulfah, M.; Trenggonowati, D.L.; Muharni, Y. (2023). Aksi mitigasi risiko rantai pasok kue kering Tando. *Journal of Systems Engineering and Management*, 2, 148. <https://doi.org/10.36055/joseam.v2i2.22221>.
- [23] Ulfah, M.M.; et al. (2024). Analisis risiko rantai pasok produk genteng menggunakan metode House of Risk. *Journal of Systems Engineering and Management*, 3, 123. <https://doi.org/10.62870/joseam.v3i2.30073>.
- [24] Ma'ruf, M.F. (2025). Pengukuran kinerja rantai pasok menggunakan pendekatan model SCOR pada perusahaan retail. *Paradoks: Jurnal Ilmu Ekonomi*, 8. <https://doi.org/10.57178/paradoks.v8i2.1213>.
- [25] Asrory, F.F. (2023). Analisis risiko rantai pasok menggunakan metode Supply Chain Operation Reference (SCOR) dan House of Risk (HOR) pada PT Indo Pusaka Berau. *Sebatik*, 27. <https://doi.org/10.46984/sebatik.v27i2.2415>.
- [26] Prakash, S.; Soni, G.; Rathore, A.P.S.; Singh, S. (2017). Risk analysis and mitigation for perishable food supply chain: A case of dairy industry. *Benchmarking: An International Journal*, 24, 2–23. <https://doi.org/10.1108/BIJ-07-2015-0070>.
- [27] Memon, M.A.; Thurasamy, R.; Ting, H.; Cheah, J.-H. (2024). Purposive sampling: A review and guidelines for quantitative research. *Journal of Applied Structural Equation Modeling*, 9, 1–23. [https://doi.org/10.47263/JASEM.9\(1\)01](https://doi.org/10.47263/JASEM.9(1)01).
- [28] Ahmad, M.; Wilkins, S. (2025). Purposive sampling in qualitative research: A framework for the entire journey. *Quality & Quantity*, 59, 1461–1479. <https://doi.org/10.1007/s11135-024-02022-5>.

- [29] Morgan, A.K.; Dogbey, E.; Arimeyaw, W.A.; Owusu, A.F.S. (2019). Effect of road transport accessibility on agricultural produce marketing and livelihoods of farmers in the Kasena-Nankana West District of Ghana. *The Journal of Development Practice*, 5, 39–46.



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