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Supply Chain Risk Mitigation Strategy in Catfish Farming Using the House of Risk Approach and Interpretive Structural Modeling

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Abstract

Research aim : *This study aims to formulate risk mitigation strategies for the supply chain of catfish farming in Kediri City, Indonesia..*

Design/Methode/Approach : *This study employs a descriptive-analytical research design with a quantitative approach based on expert judgment to analyze risks in the catfish farming supply chain. The methods used in this study are the House of Risk (HOR) and Interpretive Structural Modeling (ISM). The HOR method is applied to identify and prioritize risk sources as well as to formulate risk mitigation strategies, while the ISM method is used to analyze the relationships among mitigation strategies and to systematically determine their implementation priorities.*

Research Finding : *This study finds that risks in the catfish farming supply chain are predominantly driven by internal operational factors, particularly unstable water quality, suboptimal feed management, and dependency on feed suppliers. Further analysis indicates that the most effective mitigation strategies, based on the Effectiveness-to-Difficulty (ETD) ratio, are feed management training and the standardization of aquaculture SOPs, as they provide significant impact with relatively low implementation difficulty. The ISM analysis reveals that mitigation strategies exhibit a hierarchical structure, with aquaculture SOP standardization acting as the key driving factor.*

Theoretical contribution/Originality :

This study provides a theoretical contribution to the development of supply chain risk management studies in the agribusiness sector, particularly in catfish farming, through the integration of the HOR and ISM methods

Practitionel/Policy implication :

Practically, the findings of this study can serve as a guideline for catfish farming practitioners in designing risk mitigation strategies that are effective, efficient, and applicable. The prioritized strategies identified, such as the standardization of aquaculture SOPs and feed management training, can be directly implemented to enhance production stability and operational efficiency.

Research limitation :

This study has limitations in terms of its scope, as it focuses only on a single catfish farming business unit; therefore, the findings cannot be broadly generalized. In addition, the assessments in the HO) and ISM methods rely heavily on expert judgment, which may introduce a degree of subjectivity

Keywords :

Risk Management, Supply Chain, Catfish Farming, House of Risk, Interpretive Structural Modeling, Risk Mitigation Strategies

1. Introduction

The catfish farming industry is one of the important subsectors in freshwater aquaculture in Indonesia (1). This commodity has high economic value due to its relatively stable market demand and affordability for the general population. Catfish serves as a major source of animal protein widely consumed by various segments of society, both at the household level and in the culinary sector, such as food stalls and micro, small, and medium enterprises (MSMEs) (2). In addition, catfish farming offers several advantages compared to other aquaculture commodities, including a relatively short production cycle, simple cultivation techniques, and strong adaptability to various environmental conditions. Therefore, the catfish farming industry plays a significant role in enhancing food security, generating employment opportunities, and supporting local economic development.

In practice, this industry involves multiple stakeholders within an integrated supply chain system, ranging from seed suppliers, feed providers, farmers, collectors, distributors, to end consumers. The smooth operation of the supply chain is crucial for ensuring successful production and distribution of catfish (3). However, in reality, the catfish farming supply chain faces various risks that can disrupt both production and distribution stability (4). One example is a catfish farming business located in Kediri City, which encounters several operational risks, including fluctuations in seed quality and availability, rising feed prices, changes in water quality, fish disease outbreaks, distribution delays, and uncertainty in market demand. These risks may lead to decreased productivity, increased operational costs, and even financial losses for business actors.

Risk analysis becomes a critical component in supply chain management within the catfish farming industry (5). Risk analysis enables business actors to identify potential disruptions at each stage of the supply chain, assess the impact and likelihood of risks, and determine appropriate mitigation strategies (6). Through systematic risk analysis, farmers and supply chain actors can anticipate uncertainties, minimize potential losses, and maintain production stability.

The implementation of risk management contributes to improving operational efficiency and business competitiveness (7). By identifying the main sources of risk within the supply chain, business actors can design mitigation measures such as improving standard operating procedures (SOPs) in aquaculture practices, strengthening relationships with reliable suppliers, adopting water quality monitoring technologies, and optimizing distribution planning. These measures not only ensure smoother operations but also support long-term business sustainability. Thus, integrating risk analysis into the supply chain management of catfish farming is essential to ensure that each process within the production and distribution system operates optimally. This approach helps reduce operational disruptions while enhancing the resilience of the catfish farming industry in facing market dynamics and environmental changes.

In the catfish farming industry, the supply chain encompasses several stages, including seed procurement, feed supply, cultivation processes, harvesting, and distribution to the market. Each of these stages carries potential risks that may disrupt operations, such as delays in feed supply, inconsistent seed quality, fluctuations in water quality, disease outbreaks, and market demand volatility. Therefore, a systematic risk management approach is required to enable business actors to identify, prioritize, and design effective risk mitigation strategies. Two methods that can be applied for this purpose are the *HOR* and *ISM*.

The *HOR* method is a risk management approach designed to identify risk agents and risk events within a supply chain system. This method is an extension of the Failure Mode and Effect Analysis (FMEA) concept combined with the principles of the House of Quality. HOR is widely used in supply chain risk analysis due to its ability to prioritize the most critical risk sources. In the context of catfish farming, HOR can help identify key risks such as dependency on specific feed suppliers, instability in pond water quality, and delays in distribution. Consequently, farmers can formulate mitigation strategies such as supplier evaluation, implementation of standardized operating procedures, and adoption of environmental monitoring technologies.

After risk mitigation strategies are formulated using the HOR method, an additional approach is required to understand the relationships among these strategies and to determine the most effective implementation sequence. For this purpose, ISM method can be applied. ISM is a system analysis method used to identify contextual relationships among elements within a complex system. It helps construct a hierarchical structure, allowing the identification of key driving factors and dependent factors.

In the catfish farming industry, ISM can assist in determining which mitigation strategies should be implemented first. For example, the standardization of administrative processes and strengthening supplier management may act as key driving factors that support the implementation of other strategies, such as water quality monitoring and the use of sensor technologies. The integration of HOR and ISM provides a comprehensive approach to supply chain risk management. The HOR method plays a role in identifying and prioritizing risk sources as well as determining effective mitigation strategies, while the ISM method helps analyze relationships among strategies and structure their implementation systematically.

The integration of these two methods enables business actors to systematically identify major risks within the supply chain, determine the most effective and feasible mitigation strategies, and establish structured implementation priorities. Therefore, the application of HOR and ISM can enhance supply chain resilience, maintain production stability, and support the sustainability of catfish farming businesses amid various uncertainties in the business environment.

1.1. Statement of Problem

The catfish farming business Berkah Rezeki faces various risks in managing its supply chain that may disrupt operational continuity, reduce productivity, and threaten business sustainability. These risks arise at multiple stages, including seed procurement, feed supply, cultivation processes, and the distribution of harvested products. The primary issue is the lack of systematic identification of risk events and risk agents that significantly affect supply chain performance. Furthermore, it remains unclear which risks have the highest priority and therefore require immediate attention.

On the other hand, business actors do not yet have a strong basis for formulating effective and efficient risk mitigation strategies, particularly in determining actions that yield the greatest impact with the lowest level of implementation difficulty. The problem becomes more complex due to the limited understanding of the relationships and interdependencies among risk mitigation strategies, resulting in unstructured and suboptimal implementation.

Therefore, an analytical approach is required that is capable of identifying and prioritizing risks, formulating effective mitigation strategies, and structuring the relationships and implementation stages of these strategies in a systematic manner. Accordingly, this study focuses on identifying risks within the supply chain, determining risk priorities using the *HOR* method, formulating mitigation strategies based on the Effectiveness-to-Difficulty (ETD) analysis, and developing a hierarchical structure and implementation priorities using *ISM* to enhance the resilience and sustainability of the catfish farming supply chain.

1.2. Research Objectives

This study aims to formulate effective, structured, and applicable risk mitigation strategies within the supply chain of the Berkah Rezeki catfish farming business in order to improve operational continuity, production stability, and business sustainability. Specifically, this study seeks to identify risk events and risk agents occurring at each stage of the supply chain, including seed procurement, feed supply, cultivation processes, and the distribution of harvested products.

Furthermore, this study aims to analyze and determine the priority of risks that have the most significant impact on supply chain performance by applying the *HOR* method through the calculation of Aggregate Risk Potential (ARP) values. Based on these results, the study also seeks to formulate the most effective and efficient risk mitigation strategies using the Effectiveness-to-Difficulty (ETD) ratio analysis, thereby generating practical and feasible mitigation alternatives.

In addition, this study aims to analyze the relationships and hierarchical structure among risk mitigation strategies using the Interpretive Structural Modeling (ISM) approach in order to understand the interdependencies among strategies and to identify key driving factors within the risk mitigation system. Ultimately, this study aims to establish a systematic prioritization and implementation sequence of risk mitigation strategies, thereby enhancing supply chain resilience, maintaining production stability, and supporting the long-term sustainability of catfish farming businesses.

2. Method

This study employs a descriptive-analytical research design with a quantitative approach based on expert judgment to analyze risks in the catfish farming supply chain. The methods applied in this study are HOR and ISM. The HOR method is used to identify and prioritize risk sources as well as to formulate risk mitigation strategies, while the ISM method is utilized to analyze the relationships among mitigation strategies and to systematically determine their implementation priorities.

The HOR method is implemented in two phases, namely the identification of risk events and risk agents, and the determination of risk priorities based on the Aggregate Risk Potential (ARP) values. Subsequently, risk mitigation strategies are formulated and evaluated using the

ETD ratio to determine their level of implementation effectiveness. The resulting mitigation strategies are then analyzed using the ISM method to identify interrelationships among strategies, construct a hierarchical structure, and determine the most appropriate implementation priorities and stages. The research steps are as follows (8):

1. Supply Chain Risk Identification

At this stage, risk events and risk agents within the catfish farming supply chain are identified. The identification process covers all supply chain activities, including seed procurement, feed supply, cultivation processes, harvesting, and product distribution. The output of this stage is a list of potential risks that may affect supply chain performance.

2. Risk Analysis Using HOR Phase 1

The next step involves conducting risk analysis using HOR Phase 1. This includes assessing the severity of impacts and the likelihood of occurrence for each risk. The Aggregate Risk Potential (ARP) value is then calculated for each risk agent. These ARP values are used to determine the priority of risk sources that require immediate attention.

3. Determination of Risk Mitigation Strategies (HOR Phase 2)

After identifying priority risk agents, the next step is to formulate alternative mitigation strategies aimed at reducing the impact of these risks. Each mitigation strategy is evaluated based on its effectiveness in reducing risk and the level of difficulty in implementation. This evaluation results in the Effectiveness-to-Difficulty (ETD) ratio, which is used to determine the most effective mitigation strategies.

4. Analysis of Strategy Relationships Using ISM

The mitigation strategies generated from the HOR analysis are then further analyzed using the ISM method to examine the relationships among strategies. The ISM process includes the development of the Structural Self-Interaction Matrix (SSIM), the construction of the reachability matrix, and the formation of a hierarchical structure of mitigation strategies. This analysis aims to identify key driving strategies as well as those that are dependent on others.

5. Determination of Strategy Implementation Priorities

Based on the ISM analysis, the mitigation strategies are arranged into a hierarchical structure that reflects their implementation priorities. Strategies with high driving power are considered top priorities in the implementation of supply chain risk management.

6. Conclusion and Recommendations

The final stage involves drawing conclusions based on the analysis results. In addition, this study provides recommendations for risk mitigation strategies that can be applied by catfish farming practitioners to enhance supply chain resilience, maintain production stability, and support business sustainability.

3. Results and Discussion

Risk Analysis in the Supply Chain of the Berkah Rezeki Catfish Farming Industry.

Risk events and risk agents in the supply chain of the Berkah Rezeki catfish farming industry are identified based on the main stages of activities, namely seed procurement, feed supply, cultivation processes, harvesting, distribution, and marketing, as presented in Table 1.

Table 1. Results of Supply Chain Risk Analysis in the Berkah Rezeki Catfish Farming Industry

Activity Stage	Risk Events	Risk Agents
Seed Provision	• Delay in seed supply • Low seed quality (slow growth and high mortality) • High seed mortality at the initial stocking stage • Inconsistent seed size	• Dependence on specific seed suppliers • Lack of standardized seed quality selection • Suboptimal seed transportation processes • Fluctuations in seed availability in the market
Feed Supply	• Delay in feed delivery • Sudden increase in feed prices • Inconsistent feed quality • Insufficient feed stock in the warehouse	• Dependence on a single feed supplier • Fluctuations in feed raw material prices • Inadequate inventory management system • Lack of supplier evaluation • Unstable logistics distribution
Cultivation Process	• High fish mortality rate • Suboptimal fish growth • Disease outbreaks • Decline in water quality (pH, temperature, dissolved oxygen) • Overcrowding (excessive stocking density)	• Lack of water quality monitoring • Absence of monitoring technology (temperature/pH sensors) • Inappropriate feed management • Inadequate implementation of aquaculture SOPs • Extreme weather/climate changes
Harvesting Stage	• Non-uniform fish size • Harvest yield below target • Physical damage to fish during harvesting	• Suboptimal production planning • Non-standardized harvesting techniques • Inappropriate feeding schedule
Distribution and Marketing Stage	• Delay in delivery to the market • Decline in fish quality during distribution • Fluctuations in selling prices • Unstable market demand • Products not absorbed by the market	• Inefficient distribution system • Inadequate transportation facilities • Dependence on intermediaries (middlemen) • Limited market information • Lack of diversification in marketing channels

Source: Processed data by the researcher (2026)

Overall, risks in the supply chain of the Berkah Rezeki catfish farming business originate from upstream factors, including the quality and availability of seeds and feed; internal factors, such as cultivation and operational management; and downstream factors, including distribution and market dynamics. These risks are interrelated and may have systemic impacts on cultivation productivity, cost efficiency, and the stability of business income (9), (10).

Risk Analysis and Prioritization Using the House of Risk (HOR) Methot

1. HOR calculation (Phase 1)

a. The Aggregate Risk Potensial (ARP) value is calculated using the following formula:

$$ARP_j = O_j \times \Sigma\ (S_i \times R_{ij})$$

Where:

- ARP_j= Aggregate Risk Potential value of the j-th risk agent
- O_j= Occurrence level (*probability*) of the risk agent
- S_i= Severity level (impact) of the risk even
- R_{ij}= Correlation between risk event i and risk agent j (0, 1, 3, 10)

b. Determination of Assessment Scales

Severity (S): 1 (very low) – 10 (very high)

Occurrence (O): 1 (rare) – 10 (very frequent)

Relationship (R):

- 0 = No relationship
- 1 = Low
- 3 = Moderate
- 10 = High

c. Identification of Main Risks

Risk Events (Ei)

Table 2. Identification of Main Risk Events

Code	Risk Event	Severity (S)
E1	High fish mortality	5
E2	Suboptimal fish growth	5
E3	Delay in feed supply	5
E4	Low seed quality	3
E5	Delay in distribution	7

Risk Agents (Aj)

Table 3. Risk Agent

Code	Risk Agent	Occurrence (O)
A1	Unstable water quality	7
A2	Dependence on feed suppliers	7
A3	Inadequate seed selection	7
A4	Improper feed management	3
A5	Weak distribution system	6

d.

e. Matriks Correlation (Rij)

Table 4. Matriks Hubungan

Risk Event / Agent	A1	A2	A3	A4	A5
E1	7	9	8	9	0
E2	9	7	8	9	0
E3	1	9	0	4	1
E4	2	0	9	1	0
E5	0	1	0	1	9

f. Calculation ARP

Table 5. Calculation ARP

Risk Agent	ARP
A1 – Unstable water quality	**294**
A2 – Dependence on feed suppliers	**90**
A3 – Inadequate seed selection	**364**
A4 – Improper feed management	**490**
A5 – Weak distribution system	**414**

g. Priority Analysis (Pareto 80/20)

A3 – Inadequate seed selection (490)
A5 – Weak distribution system (414)
A2 – Dependence on feed suppliers (364)
A1 – Unstable water quality (294)
A4 – Improper feed management (90)

h. Interpretation Of Results

Table 6. Risk Priority Classification

High Priority Risk	Medium-Priority Risks	Low-Priority Risks
• A3 – Inadequate seed selection. The most critical risk as it directly affects cost efficiency. • A5 – Weak distribution system, Influences production outcomes at the harvesting stage. • A2 – Dependence on feed suppliers. A strategic risk within the supply chain	• A1 – Unstable water quality)	• A4 – Improper feed management(Relatively easier to control)

Source: Processed data by the researcher (2026)

The results of the analysis using the House of Risk method indicate that the risk agent with the highest Aggregate Risk Potential (ARP) value is unstable water quality, followed by improper feed management and dependence on feed suppliers. This finding suggests that risks originating from internal cultivation processes have the greatest influence on the operational performance of the catfish farming supply chain (11). Therefore, risk mitigation priorities should focus on controlling the aquaculture environment, optimizing feeding practices, and strengthening supplier relationship management (4).

2. HOR Calculation (Phase 2)

a. HOR Phase 2 Evaluation

The objective of this stage is to:

- Identify mitigation actions (preventive actions)
- Assess the effectiveness of each action in addressing risk agents
- Evaluate the level of difficulty of implementation
- Calculate the Effectiveness-to-Difficulty (ETD) ratio to determine the priority of mitigation strategies

Formula:

$ETD_k = \Sigma(ARP_j \times E_j)/D_k$

Where:

- ETD_k= Priority value of the k-th mitigation strategy
- ARP_j= Aggregate Risk Potential value of the j-th risk agent
- E_{jk}= Effectiveness of strategy k in mitigating risk agent (0,1,3,9)
- D_k= Level of implementation difficulty (1–10)

b. Priority Risk Agents (Input from Phase 1)

Table 7. Risk Agent Priority

Kode	Risk Agent	ARP
A1	Unstable water quality	294
A4	Improper feed management	90
A2	Dependence on feed suppliers	364
A3	Inadequate seed selection	490

c. Determination of Mitigation Strategies (Preventive Actions)

Code	**Mitigation Strategi**
PA1	Installation of water quality monitoring sensors (temperature, pH, DO)
PA2	Standardization of aquaculture SOPs
PA3	Feed management training
PA4	Evaluation and diversification of feed suppliers
PA5	Standardization of seed selection

d. Matriks Efektivitas (Ejk)

Table 8. Matriks Efektivitas (Ejk)

Risk Agent	PA1	PA2	PA3	PA4	PA5
A1 (Water)	9	3	1	1	1
A4 (Feed)	3	9	7	3	0
A2 (Supplier)	0	1	1	9	0
A3 (Seed)	0	3	1	0	9

e. Level Of Dificully (Dk)

Table 9. Level Of Dificully (Dk)

Strategi	Difficulty (Dk)
PA1	6
PA2	5
PA3	4
PA4	5
PA5	4

f. ETD Calculation Result

Table 10. ETD Calculation Result

Strategi	Total Effectiveness	ETD
PA1 – Water quality monitoring sensors	2916/6	**486**
PA3 – Feed management trainin	3526/5	**705**
PA2 – Aquaculture SOP standardization	1778/4	**444.5**
PA4 – Supplier Evaluation and diversification	3840/5	**768**
PA5 – Seed selection	4704/4	**1176**

g. Strateegi Priority Ranking

The ranking of mitigation strategies based on the ETD values is as follows:

1. PA3 – Feed management training (486)
2. PA2 – Aquaculture SOP standardization (705)
3. PA4 – Supplier evaluation and diversification (444.5)
4. PA1 – Water quality monitoring sensors (768)
5. PA5 – Seed selection standardization (1176))

h. Interpretation Of Results

Table 11. Strategy Priority

High Priority Strategi	Medium Priority Strategi	Low Priority Strategi
• Seed selection standardization High impact with relatively low cost • Water quality monitoring sensors Capable of controlling multiple risks simultaneously.	• Aquaculture SOP standardization. • Feed management training.	• upplier evaluation and diversification

Source: Processed data by the researcher (2026)

3. *ISM* for Structuring Risk Mitigation Strategy Priority Based on HOR Phase 2 Result.

a. Elemen of Analysis (ISM Input)

The mitigation strategies (results of HOR Phase 2) :

- **PA1:** Installation of water quality monitoring sensors
- **PA2:** Standardization of aquaculture SOPs
- **PA3:** Feed management training
- **PA4:** Evaluation and diversification of feed suppliers
- **PA5:** Standardization of seed selection

b. Determination of Contextual Relationship

The basic ISM question is: "*Does strategy i influence strategy j*"

Example logic:

- PA2 (SOP standardization) influences all other strategies
- PA3 (training) supports the implementation of SOPs
- PA4 (supplier evaluation) is relatively independent
- PA1 (water quality sensors) requires SOP implementation as a prerequisite

c. Structural Self-Interaction Matrix (SSIM)

Table 12. Structural Interaction Matrix (SSIM)

To	PA1	PA2	PA3	PA4	PA5
PA1	-	A	A	X	X
PA2	V	-	V	V	V
PA3	V	A	-	V	V
PA4	X	A	A	-	V
PA5	X	A	A	A	-

Where:

- V: i → j
- A: j → i
- X: mutual influence

d. Reachability Matrix (Final)

Table 13. Reachability Matrix

Strategy	PA1	PA2	PA3	PA4	PA5	Driving Power
PA1	1	0	0	1	1	3
PA2	1	1	1	1	1	**5**
PA3	1	0	1	1	1	4
PA4	1	0	0	1	1	3
PA5	1	0	0	0	1	2

e. Hierarchical Level Of Strategy

The recommended implementation sequence is as follows:

1. Aquaculture SOP standardization
2. Feed management training
3. Feed supplier evaluation
4. Technology implementation (water quality sensors)
5. Seed selection improvement

The results of the ISM analysis indicate that risk mitigation strategies in the catfish farming supply chain exhibit a systematic hierarchical structure. Aquaculture SOP standardization acts as the main driving factor, influencing the implementation of other strategies (12). Furthermore, feed management training serves as a linkage element that strengthens the implementation of operational strategies. Meanwhile, strategies such as water quality sensor installation and seed selection standardization are positioned at the dependent level, meaning their implementation largely depends on the success of strategies at previous levels. Therefore, the implementation of risk mitigation strategies should be carried out in a gradual and structured manner, starting from strengthening internal operational systems.

The Most Effective and Feasible Risk Mitigation Strategies in the Catfish Farming Supply Chain

Effective mitigation strategies should meet two main criteria:

- High effectiveness → capable of significantly reducing risks
- Low implementation difficulty → easy to apply in terms of cost, human resources, and time

Formula:

$$ETD = \frac{Efektivitas}{Kesulitan}$$

A higher ETD value indicates a higher priority for the corresponding mitigation strategy. The formulation of risk mitigation strategies was conducted using the ETD ratio analysis within HOR method. The results show that the strategies with the highest ETD values are feed management training and aquaculture SOP standardization, as these strategies have high effectiveness in reducing risks while requiring relatively low implementation effort (13). Meanwhile, strategies such as supplier evaluation and diversification and water quality sensor installation demonstrate high effectiveness but require greater resource investment. Therefore, the recommended risk mitigation approach is a phased implementation strategy, starting with strengthening internal operational systems, followed by supply chain reinforcement, and finally the application of supporting technologies. This approach produces mitigation alternatives that are not only effective but also realistic and efficient for application in catfish farming systems (14), (15).

The prioritization and implementation stages of risk mitigation strategies were developed by integrating the results of HOR and ISM analysis. The findings indicate that strategies with high effectiveness and strong driving roles, such as aquaculture SOP standardization and feed management training, should be prioritized in the initial implementation stage (16). Subsequently, supply chain strengthening strategies such as supplier evaluation and diversification are applied in the intermediate stage to enhance system resilience. Finally, technology-based strategies such as water quality sensor installation and seed selection improvement are implemented in the final stage as a form of system optimization. This phased approach enables the implementation of risk mitigation strategies that are more realistic, efficient, and sustainable in improving production stability and supply chain resilience in catfish farming (17).

4. Conclusion

This study shows that the supply chain in the Berkah Rezeki catfish farming business is exposed to various risks occurring at each stage, including seed procurement, feed supply, cultivation processes, and distribution. Based on the results of HOR analysis, it is found that the most dominant risks originate from internal operational factors, particularly unstable water quality, suboptimal feed management, and dependence on feed suppliers. In addition, the analysis also indicates that the most effective mitigation strategies are feed management training and aquaculture SOP standardization, as these strategies have a significant impact on risk reduction with relatively low implementation difficulty.

This study provides both theoretical and practical contributions. Theoretically, it strengthens the body of knowledge on supply chain risk management in the agribusiness sector by integrating HOR and ISM methods into a single integrated approach. Practically, the findings of this study can serve as a reference for catfish farming practitioners in designing more structured, effective, and easily applicable risk mitigation strategies. The novelty of this study lies in the integration of these two methods, which enables the determination of both strategy priorities and their implementation sequence in a systematic manner.

However, this study has several limitations, particularly in terms of its scope, as it is conducted on a single catfish farming business unit; therefore, the findings cannot be widely generalized. In addition, the use of expert judgment in risk assessment may introduce subjectivity. Therefore, future research is recommended to expand the scope of study to multiple locations and combine quantitative methods with broader empirical data to produce more accurate and representative results.

Content Attribution (If you use AI assistance):

The author acknowledges the use of ChatGPT (GPT-5.3, developed by OpenAI) in the process of literature synthesis, research structuring, data analysis support, and academic writing in this study.

The AI application serves as a supporting tool to assist in generating ideas, structuring arguments, and synthesizing theoretical and methodological concepts related to supply chain risk management, particularly the application of *HOR* and *ISM*. It is important to note that the AI-generated content is not copied verbatim but has been thoroughly reviewed, revised, and refined by the author to ensure the accuracy, validity, and academic integrity of the information presented.

The author exercised independent judgment in interpreting results, validating analytical processes, and ensuring that the research findings accurately reflect the actual conditions of the object under study. Therefore, the final outcomes of this research represent a collaborative effort between human expertise and AI-assisted support.

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