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Operational Performance and Supply Chain Risk Assessment in SME Vannamei Shrimp Farming: A Multiple-Case Study Using SCOR and FMEA

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Abstract. Small and medium-sized enterprise (SME) shrimp farms play an important role in Indonesia's aquaculture sector; however, many continue to experience operational inefficiencies, rising production costs, and supply chain vulnerabilities that reduce profitability and long-term sustainability. Existing studies have examined individual operational challenges in aquaculture, yet few have adopted an integrated framework capable of simultaneously diagnosing performance gaps and prioritizing operational risks. This study addresses this gap by integrating the Supply Chain Operations Reference (SCOR) model and Failure Mode and Effects Analysis (FMEA) to evaluate operational performance and supply chain risks in three vannamei shrimp farming SMEs located in Tegal, Central Java. A qualitative multiple-case study approach was employed using interviews, field observations, operational records, SCOR process mapping, and FMEA risk assessment. The findings reveal that the most significant weaknesses are concentrated in the internally focused SCOR attributes of Cost and Asset Management, while Reliability, Responsiveness, and Agility generally perform better. Farm C demonstrated the strongest overall operational performance due to disciplined operational practices, structured data management, supplier diversification, and systematic monitoring systems. FMEA analysis identified high-priority risks associated with night-time dissolved oxygen control, post-harvest turnaround delays, feed management, inventory handling, and operational data management. The integration of SCOR and FMEA provides complementary insights whereby SCOR identifies performance deficiencies while FMEA prioritizes their underlying causes. This study contributes to the literature by demonstrating the applicability of a combined SCOR–FMEA framework in aquaculture SMEs and provides practical recommendations for improving operational efficiency, supply chain resilience, and farm profitability.

Keywords: Aquaculture; FMEA; SCOR; Shrimp Farming; Supply Chain Management.

1. BACKGROUND

The fisheries sector remains a strategic contributor to Indonesia's economy and food security. However, national fisheries production has experienced a declining trend over recent years. In 2023, production reached only 24.7 million tons, significantly below the national target of 30.37 million tons. Factors contributing to this gap include weak management systems, increasing production costs, inadequate infrastructure, environmental degradation, and climate uncertainty (KKP, 2024).

Vannamei shrimp (Litopenaeus vannamei) has emerged as one of Indonesia's most important aquaculture commodities due to its high productivity and export potential. Despite its economic significance, many shrimp farming SMEs continue to experience operational inefficiencies that negatively affect profitability and sustainability. Common challenges include uncertainty in post-larvae (PL) supply, inefficient feed utilization, excessive electricity consumption, weak inventory control, and prolonged pond preparation periods.

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Feed typically represents 60–70% of total production costs (KKP, 2022). While the ideal Feed Conversion Ratio (FCR) ranges from 1.2–1.4 (FAO, 2017), many SMEs operate at FCR levels between 1.6 and 1.9, resulting in substantial cost overruns. Similarly, ineffective pond preparation and delayed seed arrival often create idle production capacity and reduce annual harvest potential.

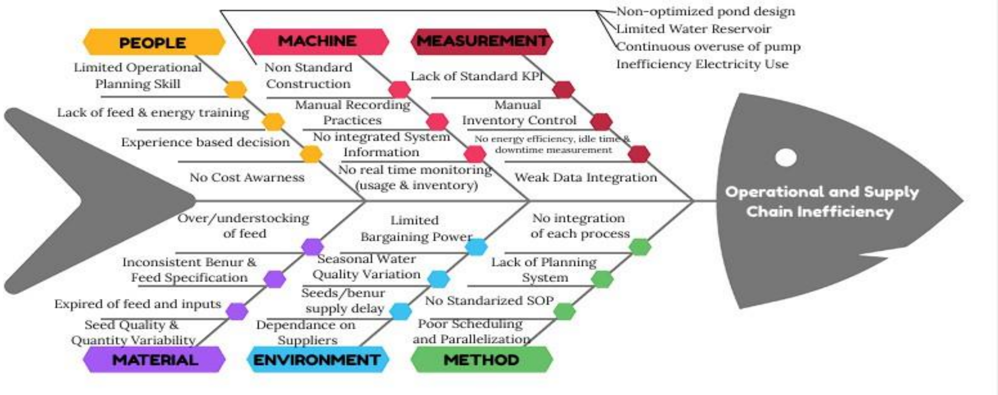

Figure 1. Issue mapping of vannamei shrip farms SME.

Although previous studies have investigated aquaculture supply chains, limited research has integrated operational performance assessment with systematic risk prioritization. Therefore, this study combines the Supply Chain Operations Reference (SCOR) framework and Failure Mode and Effects Analysis (FMEA) to identify performance gaps and prioritize improvement initiatives within SME shrimp farming operations.

2. THEORETICAL REVIEW

Supply Chain Management in Aquaculture SMEs

Supply Chain Management (SCM) refers to the coordination of material, information, and financial flows across organizations to deliver value efficiently (Christopher, 2016). In shrimp farming, SCM encompasses hatchery procurement, feed sourcing, cultivation, harvesting, and product distribution.

Unlike large integrated aquaculture companies, SMEs often operate with limited managerial resources and fragmented decision-making processes. This condition increases vulnerability to operational disruptions and supply uncertainties (Bush et al., 2019). Previous studies highlight feed inefficiency, inventory mismanagement, and supplier dependency as major contributors to performance deterioration in aquaculture SMEs (Nguyen et al., 2021; Wibowo & Putri, 2020).

Supply Chain Operations Reference (SCOR)

The SCOR model developed by APICS provides a standardized framework for evaluating supply chain performance through six processes: Plan, Source, Make, Deliver, Return, and Enable (APICS, 2017). SCOR enables organizations to assess performance through five dimensions: reliability, responsiveness, agility, cost, and asset management efficiency. The framework has been widely applied in manufacturing and agribusiness sectors but remains underutilized in aquaculture SMEs.

Failure Mode and Effects Analysis (FMEA)

FMEA is a proactive risk assessment tool used to identify potential failures and prioritize corrective actions (Stamatis, 2003). Risks are evaluated using:

[RPN= Severity\times Occurrence\times Detection]……………………………………………(i)

The resulting Risk Priority Number (RPN) enables managers to focus on high-impact operational problems. In aquaculture environments characterized by biological and environmental uncertainty, FMEA provides a structured mechanism for risk mitigation and continuous improvement.

Research Framework

This study integrates SCOR and FMEA. SCOR identifies operational performance gaps, while FMEA prioritizes underlying failure modes. The combined framework provides a comprehensive mechanism for diagnosing inefficiencies and formulating improvement strategies for shrimp farming SMEs.

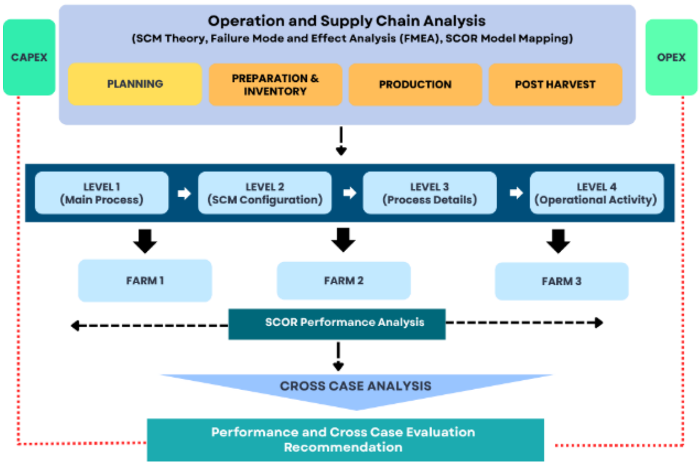

Figure 2. Proposed conceptual framework.

3. RESEARCH METHODOLOGY

This research adopts an interpretivist paradigm and employs a qualitative multiple-case study approach (Yin, 2018). Three intensive vannamei shrimp farms located in Tegal, Central Java, were selected using purposive sampling.

Data collection consisted of (1) semi-structured interviews, (2) field observations, and (3) operational records and company documents. The selected farms differed in operational scale and management maturity, allowing comparative analysis.

Data analysis was conducted in four stages: (1) thematic analysis following Braun and Clarke (2006), (2) SCOR process mapping, (3) SCOR performance evaluation, and (4) FMEA risk assessment. Performance was evaluated using a four-point rubric ranging from Very Poor (1) to Best Practice (4). Five SCOR dimensions were assessed: reliability, responsiveness, agility, cost, and asset management efficiency.

Trustworthiness was ensured through triangulation, member checking, audit trails, and cross-case comparison.

4. RESULTS AND DISCUSSION

SCOR Performance Assessment

The comparative SCOR analysis revealed substantial differences among the three farms. Farm C consistently outperformed Farms A and B across all dimensions. Higher performance was associated with better monitoring practices, diversified suppliers, multiple buyer channels, and structured operational planning. Farm B recorded the weakest performance, particularly in responsiveness and cost. The farm experienced significant losses due to delayed detection of dissolved oxygen (DO) problems and ineffective feed management.

Table 1. Comparative SCOR analysis of the three farms.

SCOR Dimension	Farm A	Farm B	Farm C
Reliability	**2.25** Below Std	**2.25** Below Std	**3.25** Adequate
Responsiveness	**2.5** Below Std	**1.75** Very Poor	**3.00** Adequate
Agility	**2.00** Below Std	**2.00** Below Std	**3.50** Adequate
Cost	**1.50** Very Poor	**1.50** Very Poor	**2.50** Below Std
Asset Management	**1.75** Very Poor	**1.75** Very Poor	**3.00** Adequate
Overall Score	**2.00** Below Std	**1.85** Very Poor	**3.05** Adequate

FMEA Analysis

FMEA identified critical operational risks across the farms. Farm B exhibited the highest RPN score, indicating greater operational vulnerability. The most critical failure modes included: absence of standardized SOPs, delayed seed supply, excessive stocking density, weak feed inventory management, and lack of real-time operational monitoring.

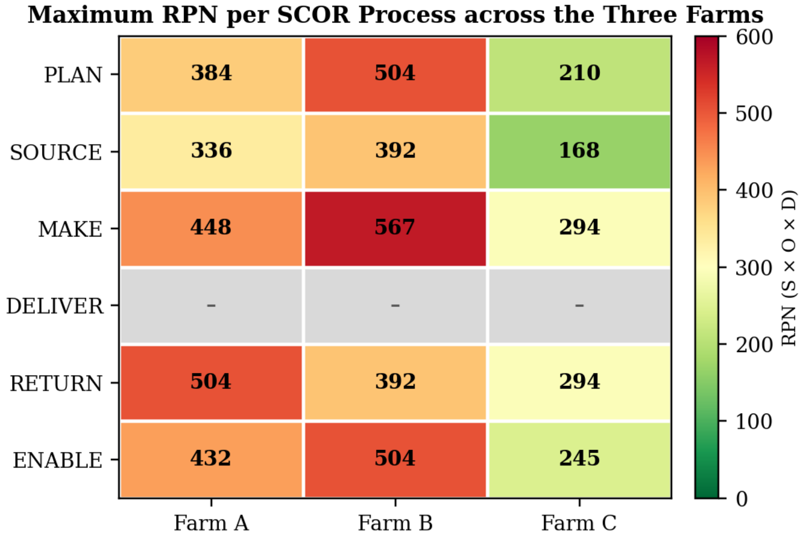

Figure 3. Heat map of RPN per SCOR analysis.

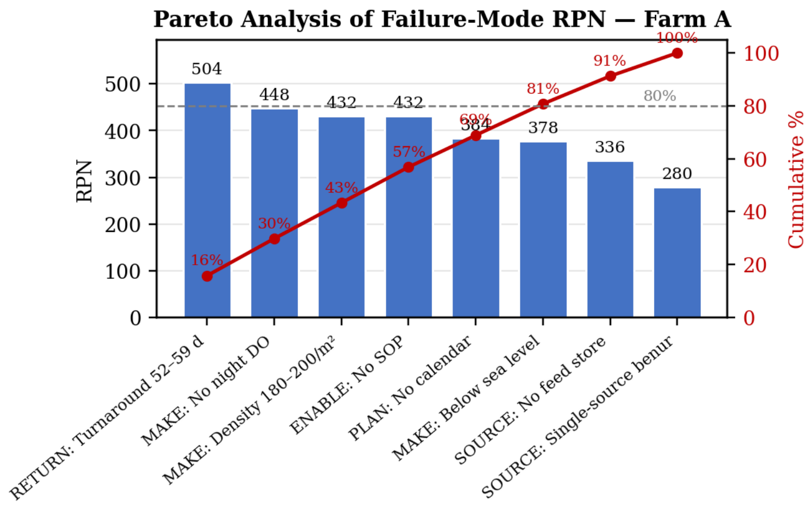

Figure 4. Pareto analysis of failure-mode RPN for Farm A.

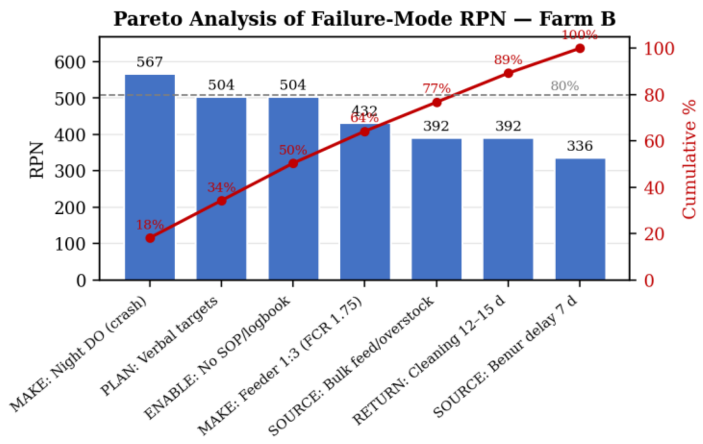

Figure 5. Pareto analysis of failure-mode RPN for Farm B.

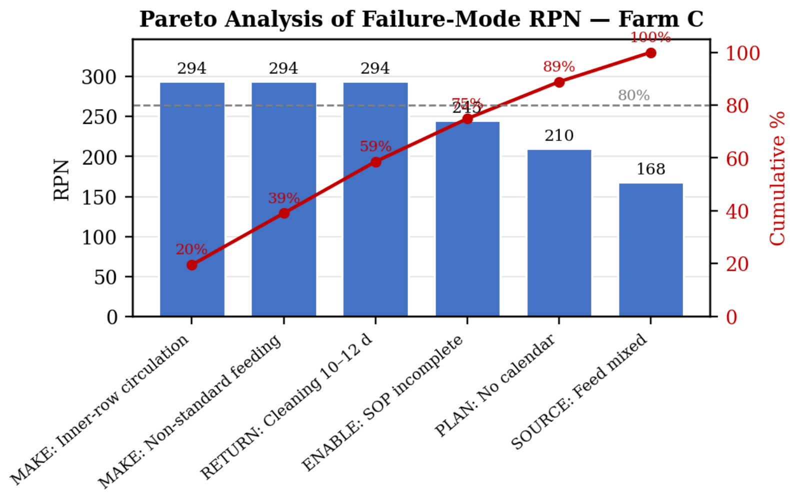

Figure 6. Pareto analysis of failure-mode RPN for Farm C.

Cross-Case Gap Analysis

The cross-case analysis was conducted to identify recurring operational patterns, distinguish practices associated with superior performance, and determine the underlying factors responsible for performance differences among the three case farms. Following Yin (2018), the analysis examined convergent patterns, divergent practices, and root causes across the cases to generate analytical insights beyond individual farm-level observations.

Convergent Patterns

Several operational weaknesses were consistently observed across all three farms. First, none of the farms operated under fully formalized Standard Operating Procedures (SOPs), resulting in a high degree of dependence on owner experience and tacit knowledge. Second, supplier relationships remained largely transactional, with limited use of formal agreements or long-term procurement planning, particularly for post-larvae (PL) supply and critical production inputs. Third, pond preparation and turnaround activities frequently exceeded recommended durations, reducing annual production capacity and increasing idle asset time. Fourth, feed conversion ratios (FCR) generally remained above industry benchmarks, indicating inefficiencies in feeding practices and biomass estimation. Finally, all farms demonstrated limited use of real-time performance monitoring systems and key performance indicators (KPIs), restricting their ability to detect operational deviations before they developed into significant losses.

These recurring issues suggest that operational inefficiencies within SME shrimp farming are not isolated incidents but systemic challenges associated with limited management formalization, weak process standardization, and inadequate performance measurement systems. Similar observations have been reported in aquaculture SMEs, where fragmented planning and limited operational visibility contribute to cost escalation and performance instability (Bush et al., 2019; Nguyen et al., 2021).

Divergent Practices

Despite facing similar environmental and market conditions, Farm C consistently achieved superior performance across all SCOR dimensions. Cross-case comparison revealed several operational practices that distinguished Farm C from the other farms.

Farm C conducted water-quality monitoring four times per day, enabling early detection of dissolved oxygen fluctuations and other environmental risks. The farm also implemented advance hatchery ordering approximately 30–45 days before stocking, reducing the likelihood of production delays caused by post-larvae shortages. Feed procurement was performed using rolling replenishment schedules rather than reactive purchasing, improving inventory control and reducing the risk of stockouts. Furthermore, Farm C maintained multiple buyer channels, which enhanced marketing flexibility and reduced dependence on a single purchaser. The farm also adopted lower stocking densities, which contributed to improved survival rates and more stable production outcomes.

These practices collectively enhanced operational control, reduced uncertainty, and improved responsiveness to operational disruptions. The findings indicate that superior performance is associated not solely with farm size or production capacity but with the implementation of disciplined operational management practices and structured decision-making processes.

Root Cause Analysis

The cross-case analysis identified five dominant root causes that explain the majority of operational inefficiencies and supply chain risks observed across the cases.

The first root cause was limited management formalization. Operational activities were frequently dependent on individual experience rather than standardized procedures, creating inconsistencies in execution and reducing organizational learning. The second root cause involved suboptimal physical infrastructure, including limitations in reservoir systems, aeration arrangements, and supporting facilities that affected production efficiency and resource utilization.

The third root cause was workforce-to-scale imbalance. As production capacity increased, labor allocation and operational supervision did not always scale proportionately, reducing monitoring effectiveness and increasing operational vulnerability. The fourth root cause involved weak upstream supply chain management, particularly supplier dependency, inconsistent post-larvae availability, and limited procurement planning. Finally, weak performance monitoring and data management systems restricted managerial visibility and delayed corrective actions, causing operational issues to be detected only after substantial losses had occurred.

Collectively, these findings demonstrate that operational inefficiencies in SME shrimp farming arise from interconnected managerial, infrastructural, and supply chain factors rather than isolated technical failures. Therefore, improvement initiatives should prioritize systemic capability development rather than addressing individual operational symptoms in isolation.

Best Practices and Improvement Priorities

Building upon the cross-case findings, this study identified a set of adoptable best practices that can be implemented by SME shrimp farms to improve operational performance and reduce supply chain risk exposure.

The first improvement priority concerns management formalization. The development and implementation of standardized operating procedures for pond preparation, feeding, water-quality monitoring, harvesting, and post-harvest activities can reduce operational variability and improve process consistency. Standardization also facilitates workforce training and strengthens organizational learning.

The second priority involves strengthening upstream supply chain management. Farms should establish longer-term relationships with hatcheries and critical suppliers through advance procurement planning and supplier diversification. Reducing dependence on a single supplier can improve supply continuity and minimize production delays caused by post-larvae shortages.

The third priority focuses on operational monitoring and data management. The adoption of routine KPI tracking for feed conversion ratio, survival rate, electricity consumption, water-quality parameters, and pond turnaround time can improve managerial visibility and support data-driven decision-making. Improved monitoring enables earlier detection of performance deviations and facilitates proactive corrective actions.

The fourth priority relates to feed and inventory management. Structured feed planning, rolling procurement schedules, and inventory control procedures can reduce waste, prevent stockouts, and improve cost efficiency. Given that feed represents the largest production cost component in shrimp farming operations, improvements in feed management are expected to generate significant financial benefits.

The fifth priority addresses asset utilization and operational discipline. Standardized pond preparation schedules, preventive maintenance programs, and more efficient resource allocation can reduce idle production time and improve asset management performance. These practices are particularly important given that Cost and Asset Management were identified as the weakest SCOR dimensions across the cases.

Based on the implementation roadmap developed in this study, improvement initiatives should be phased according to resource requirements and implementation complexity. Short-term initiatives should focus on SOP development, KPI establishment, and monitoring improvements. Medium-term initiatives should emphasize supplier management enhancement, inventory system improvement, and workforce capability development. Long-term initiatives should prioritize infrastructure upgrades, digitalization, and advanced performance management systems. Collectively, these initiatives provide a practical pathway for improving operational efficiency, reducing supply chain risk, and enhancing the long-term sustainability of SME shrimp farming enterprises.

Table 2. Consolidated best practices for the three farms.

Code	SCOR Process	Best Practice	Implementation Ease	Target Farm	Impact
BP-01	ENABLE	A standardized, uniform logbook format for all feeders, with a 1-page daily checklist per pond (feed target, check-tray results, shrimp condition, water quality, incident notes).	Easy / Free	A, B, C	High
BP-02	MAKE	Routine nighttime DO monitoring at 22:00, not only when a problem is indicated.	Easy / IDR 800k–2M (DO meter and alarm)	A, B	Critical
BP-03	SOURCE	A system for returning leftover feed to the supplier, exchanged for new stock the next cycle.	Easy / no extra cost	B, C	Moderate
BP-04	PLAN	Mid-cycle performance evaluation every 2 weeks using sampling data (estimated FCR, estimated SR, water condition).	Easy / Free (Google Sheets or paper)	A, B	High
BP-05	SOURCE	Order Benur at least 30–45 days before stocking, with confirmation from a backup hatchery.	Easy / No cost	A, B	High
BP-06	SOURCE	Hatchery-performance evaluation based on early SR data (DOC 7) each cycle.	Easy / Free	A, B	Moderate
BP-07	ENABLE	A preventive-maintenance schedule for the generator testing and servicing before each cycle begins.	Easy / IDR 200k–500k per service	A (critical)	Critical
BP-08	MAKE	Reduce stocking density to 100–150/m² with a recalculation of economic viability.	Moderate / No extra cost (less Benur volume)	A (critical), B	Critical
BP-09	SOURCE	A simple MoU/agreement with Benur and feed suppliers covering price, quantity, schedule, and replacement for late delivery.	Moderate / Requires negotiation time	A, B, C	High
BP-10	ENABLE	Develop SOPs for 3 critical processes: (1) daily feeder checklist, (2) water-quality procedure (low DO), (3) post-harvest pond-preparation procedure.	Moderate / IDR 0–500k (printing and lamination)	A, B, C	Critical
BP-11	MAKE	A laminated feed-dose reference table per pond size (500–1,200 m²) and DOC, posted at each pond.	Easy / IDR 0–50k	C (critical), A, B	High
BP-12	SOURCE	Diversify feed-purchasing across 2 brands and buy every 30 days (rolling), not bulk at cycle start.	Easy / No extra cost	B (critical), A	High
BP-13	DELIVER	Develop 3 marketing channels: collectors (volume), processors (premium), plus the local market (grade B).	Difficult / Requires networking and quality investment	A, B	High
BP-14	PLAN	Stagger stocking schedules across ponds (2–3 weeks apart) to avoid simultaneous harvests and distribute the workload more evenly.	Easy / No cost	A, B	Moderate
BP-15	MAKE	Phased / staged aeration schedule (16–18 h at low DOC; 24 h only at high DOC) to cut electricity use.	Easy / No extra cost	A, B	High

Figure 7. SME Shrimp Farming Performance Analysis Summary.

5. CONCLUSION AND RECOMMENDATIONS

This study evaluated operational performance and supply chain risks in three SME-scale vannamei shrimp farms in Tegal, Central Java, using an integrated Supply Chain Operations Reference (SCOR) and Failure Mode and Effects Analysis (FMEA) framework. The findings revealed substantial differences in operational performance among the three farms. Farm C achieved the highest overall SCOR score, while Farm B demonstrated the weakest performance. Across all cases, the most significant performance deficiencies were concentrated in the internally focused SCOR dimensions of Cost and Asset Management, indicating persistent challenges in resource utilization, production efficiency, and operational planning.

The FMEA assessment further revealed that operational risks were concentrated in several critical areas, including dissolved oxygen management, pond turnaround activities, feed management, inventory control, supplier reliability, and operational data management. Farm B exhibited the highest overall risk exposure, reflected by the highest Risk Priority Number (RPN) values across multiple SCOR processes. The integration of SCOR and FMEA provided complementary insights by simultaneously identifying performance deficiencies and prioritizing their underlying operational causes.

Cross-case analysis identified several recurring weaknesses shared across the three farms, including the absence of fully formalized Standard Operating Procedures (SOPs), weak supplier coordination, prolonged pond preparation periods, feed conversion ratios above industry benchmarks, and limited use of real-time performance monitoring systems. These recurring patterns indicate that operational inefficiencies in SME shrimp farming are largely systemic rather than isolated technical problems.

The analysis also identified several distinguishing practices associated with superior performance. Farm C consistently implemented more structured operational controls, including frequent water-quality monitoring, advance hatchery procurement planning, rolling feed replenishment practices, diversified buyer networks, and more disciplined production management. These practices contributed to higher operational performance, lower risk exposure, and stronger supply chain resilience.

Furthermore, the study identified five dominant root causes underlying operational inefficiencies across the cases: limited management formalization, suboptimal physical infrastructure, workforce-to-scale imbalance, weak upstream supply chain management, and inadequate performance monitoring and data management systems. These root causes explain a substantial proportion of the performance gaps and operational risks observed throughout the farms.

From a practical perspective, the study proposes several improvement priorities, including the formalization of operational procedures, supplier diversification, enhanced KPI-based performance monitoring, improved inventory and feed management systems, and more structured asset utilization practices. These recommendations were translated into a phased implementation roadmap consisting of short-term, medium-term, and long-term initiatives to support sustainable operational improvement.

This study contributes to the literature by demonstrating the applicability of an integrated SCOR–FMEA framework in the context of aquaculture SMEs. Unlike studies that focus solely on performance measurement or risk assessment, the present research combines operational performance evaluation, risk prioritization, cross-case comparison, root-cause identification, and best-practice extraction within a single analytical framework. The findings provide both theoretical and managerial insights for improving operational efficiency, reducing supply chain vulnerability, and strengthening the long-term sustainability of SME shrimp farming enterprises.

Recommendations

Future improvement efforts should prioritize the establishment of standardized operating procedures, implementation of real-time performance monitoring systems, and development of more structured supplier management practices. Particular attention should be given to improving feed management, pond turnaround efficiency, and operational data recording, as these areas demonstrated significant influence on both SCOR performance and FMEA risk levels.

For future research, broader studies involving larger samples, different aquaculture regions, and additional performance indicators are recommended to enhance generalizability and further validate the integrated SCOR–FMEA approach. Quantitative validation of the identified root causes and best practices may also provide deeper insights into the determinants of operational performance in aquaculture SMEs.

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