OPERATIONAL PRIORITIES SUPPORTING INTENSIVE SHRIMP FARM PRODUCTIVITY USING THE ANALYTIC HIERARCHY PROCESS

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ABSTRACT

Intensive whiteleg shrimp farming requires managers to allocate limited labor, equipment, energy, and digital capacity across interdependent production activities. This study prioritized operational criteria supporting shrimp farm productivity at a commercial intensive Litopenaeus vannamei operation in Purworejo, Central Java, Indonesia. Five purposively selected experts representing strategic, production, technical, water-quality, and feeding functions completed semi-structured interviews and pairwise-comparison questionnaires during May-July 2026. The Analytic Hierarchy Process was used to aggregate judgments by geometric mean, calculate local and global priority weights, and test consistency. Operational Efficiency received the highest main-criterion weight (58.57%), followed by Digital Feeding Management (33.73%) and Water Quality Control (7.70%). Labor Productivity was the leading global sub-criterion (22.49%), followed by Equipment Maintenance Management (15.89%) and Energy Utilization Efficiency (11.30%). Within feeding management, Feeding Frequency ranked first; within water-quality control, Aeration and Water Circulation Effectiveness ranked marginally above pH Stability Control. The consistency ratios for the main criteria, feeding, water-quality, and operational-efficiency matrices were 0.025, 0.093, 0.089, and 0.090, respectively, all below 0.10. The results indicate that cross-cutting operational capability should receive first managerial attention, while feeding and water-quality safeguards must continue as essential operating controls. The framework supports transparent resource allocation but represents expert priorities rather than causal effects on biological productivity.

Keywords: *Analytic Hierarchy Process; Intensive Aquaculture; Operational Efficiency; Shrimp Productivity; Whiteleg Shrimp.*

INTRODUCTION

Whiteleg shrimp (Litopenaeus vannamei) is a high-value aquaculture commodity whose intensive production depends on the coordinated performance of feeding, environmental control, equipment, energy, and labor. The growth of aquaculture has strengthened its contribution to food supply and rural economies, but intensification also increases operational interdependence and exposure to failure. A delayed feeding adjustment can increase waste; excessive organic loading can worsen water conditions; and aerator or pump downtime can quickly affect survival and growth. Consequently, farm productivity is not only a biological outcome but also a result of how reliably the production system is managed (Boyd & McNevin, 2021; Joffre et al., 2018).

Feed is a major operating cost in shrimp culture, and feeding frequency, dosage, and timing influence both growth and pond waste loading. Digital records and automatic feeders can improve repeatability and give managers faster feedback, but these technologies still depend on suitable operating procedures and capable staff. Water quality is equally indispensable: dissolved oxygen, pH, ammonia, nitrite, circulation, and aeration affect shrimp health and the carrying capacity of intensive ponds (Boyd & Tucker, 1998; Hargreaves, 1998). Operational efficiency connects these biological controls to daily execution through labor productivity, standard operating procedure compliance, energy use, and equipment maintenance.

Previous aquaculture studies commonly examine feeding, water quality, digitalization, or resource efficiency separately. This separation is useful for technical diagnosis but

provides limited guidance when managers must choose among competing investments. In practice, a farm may have to decide whether the next improvement budget should support staff capability, preventive maintenance, automated feeding, sensors, or other controls. The problem is therefore one of managerial prioritization rather than simple technical importance. A lower priority does not mean that a criterion is biologically optional; it indicates where additional managerial attention is judged to produce the greatest support under the conditions studied.

The Analytic Hierarchy Process (AHP) is suited to this problem because it decomposes a decision goal into criteria and sub-criteria, elicits pairwise expert judgments, and converts them into transparent priority weights while checking logical consistency (Saaty, 2008; Vaidya & Kumar, 2006). This study therefore aimed to: (1) determine the relative priorities of Digital Feeding Management, Water Quality Control, and Operational Efficiency; (2) rank the twelve associated sub-criteria; and (3) translate the rankings into a practical decision-support framework for intensive shrimp-farm management.

MATERIALS AND METHODS

Research design, location, and period. This was a qualitative decision-support case study using expert judgment and AHP. Data were collected from May to July 2026 at intensive L. vannamei farming operations managed by PT LaMaison Interior Indo in Purworejo, Central Java, Indonesia. Productivity was treated as the managerial goal of the hierarchy, not as a statistically modeled dependent variable. The study therefore estimates relative priorities and does not claim causal effect sizes.

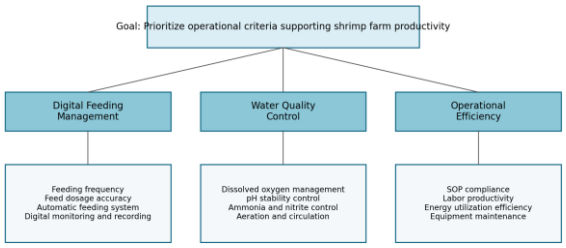
Expert selection and data collection. Purposive sampling identified five participants with at least three years of relevant experience and direct involvement in farm decisions. Their roles covered ownership, production supervision, field technology, water-quality control, and feeding. Semi-structured interviews were used to validate the hierarchy and interpret operational conditions. Each participant then completed pairwise comparisons of the three main criteria and of four sub-criteria within each main criterion using Saaty's 1-9 fundamental scale.

Table 1. Profile of expert respondents

Code	Role	Experience	Primary expertise
E1	Owner/co-owner	7 years	Strategy and investment
E2	Production supervisor	4 years	Production and pond operations
E3	Field technician	11 years	Equipment and aeration
E4	Water-quality staff	9 years	DO, pH, ammonia monitoring
E5	Senior feeder	4 years	Feeding and feed efficiency

Hierarchy development. Literature and expert consultation were used to define three main criteria and twelve sub-criteria. Digital Feeding Management comprised Feeding Frequency, Feed Dosage Accuracy, Automatic Feeding System, and Digital Monitoring and Recording. Water Quality Control comprised Dissolved Oxygen Management, pH Stability Control, Ammonia and Nitrite Control, and Aeration and Water Circulation Effectiveness. Operational Efficiency comprised SOP Compliance, Labor Productivity, Energy Utilization Efficiency, and Equipment Maintenance Management

Figure 1. AHP hierarchy used to prioritize operational criteria supporting shrimp farm productivity



AHP calculation. For each reciprocal pairwise matrix A=[aij], priority vectors were obtained by normalization/eigenvector calculation. Individual expert priorities were combined using the geometric mean and normalized to sum to 1. Global sub-criterion weights were calculated by multiplying each local sub-criterion weight by its parent criterion weight. Judgment consistency was evaluated as CI=(lambda_max-n)/(n-1) and CR=CI/RI, where RI is Saaty's random index. A matrix was accepted when CR was no greater than 0.10 (Saaty, 2008). Calculations were completed and checked in Microsoft Excel.

Quality and ethics. Credibility was supported through role-diverse expertise, interview clarification, document review, geometric-mean aggregation, and consistency testing. The study did not experiment on, handle, or sample aquatic animals; therefore, animal ethics approval was not applicable. Participants provided informed consent, and respondent identities are represented by codes.

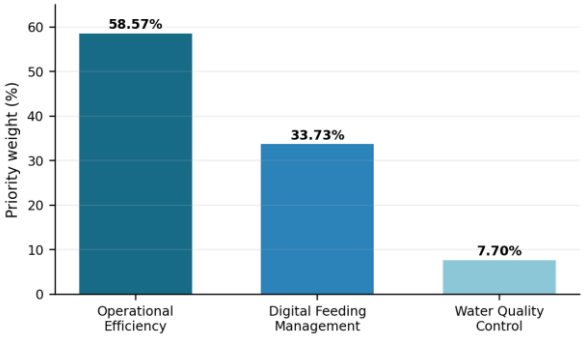
RESULTS AND DISCUSSIONS

Main-criterion priorities. Operational Efficiency dominated the aggregated model with a weight of 0.5857, followed by Digital Feeding Management at 0.3373 and Water Quality Control at 0.0770 (Table 2; Figure 2). The main-criteria CR was 0.025, indicating a coherent group judgment. The result suggests that the experts saw labor, equipment reliability, energy use, and operating discipline as cross-cutting capabilities that enable feeding and environmental-control tasks to be carried out consistently.

Table 2. Aggregated priority weights of the main criteria

Criterion	E1	E2	E3	E4	E5	Final
Digital feeding	0.296	0.296	0.532	0.28	0.296	0.3373
Water quality	0.069	0.069	0.102	0.073	0.069	0.077
Operational efficiency	0.636	0.636	0.366	0.647	0.636	0.5857

Figure 2. Priority weights of the three main operational criteria



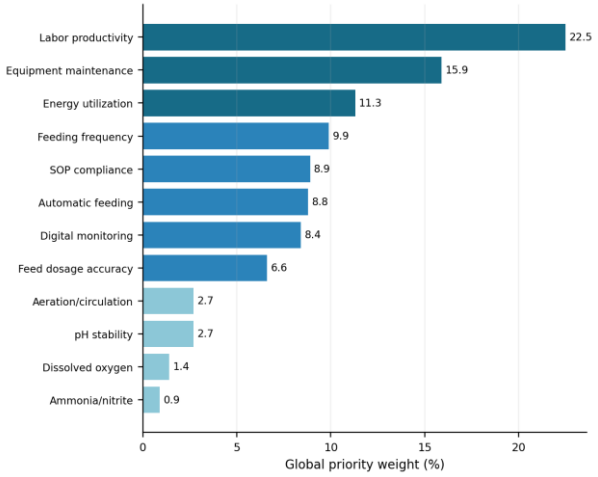
The dominance of Operational Efficiency does not negate the biological importance of water quality. Rather, it reflects the experts' assessment of where additional managerial attention is most urgent in the studied operation. Stable water quality is produced through daily actions: correct feeding, reliable aeration, rapid response, maintenance, monitoring, and SOP execution. In this sense, operational efficiency functions as an enabling capability. Poor maintenance or delayed labor action can immediately weaken environmental control, whereas reliable processes help sustain acceptable pond conditions (Boyd & Tucker, 1998; Heizer et al., 2020).

Local and global sub-criterion priorities. Labor Productivity was the highest global priority (0.2249), followed by Equipment Maintenance Management (0.1589) and Energy Utilization Efficiency (0.1130). These three operational-efficiency items together accounted for almost half of the total model weight. The pattern is plausible in intensive culture, where human response and continuously operating aerators, pumps, feeders, and generators are essential to production continuity. Preventive maintenance reduces avoidable downtime, while capable staff improve the timeliness and accuracy of feeding, monitoring, and corrective actions.

Table 3. Local and global priority weights of all sub-criteria

Parent criterion	Sub-criterion	Local	Global	Rank
Operational efficiency	Labor productivity	0.384	0.2249	1
Operational efficiency	Equipment maintenance	0.271	0.1589	2
Operational efficiency	Energy utilization	0.193	0.113	3
Digital feeding	Feeding frequency	0.294	0.0992	4
Operational efficiency	SOP compliance	0.152	0.0891	5
Digital feeding	Automatic feeding system	0.26	0.0877	6
Digital feeding	Digital monitoring/recording	0.249	0.084	7
Digital feeding	Feed dosage accuracy	0.196	0.0661	8
Water quality	Aeration and circulation	0.349	0.0269	9
Water quality	pH stability control	0.346	0.0266	10
Water quality	Dissolved oxygen management	0.182	0.014	11
Water quality	Ammonia and nitrite control	0.122	0.0094	12

Figure 3. Global ranking of the twelve operational sub-criteria



Within Digital Feeding Management, Feeding Frequency ranked first locally (0.294), followed by Automatic Feeding System (0.260), Digital Monitoring and Recording (0.249), and Feed Dosage Accuracy (0.196). This ordering emphasizes the operating rhythm of feed delivery rather than technology alone. Automatic feeders and digital records are valuable when they support timely adjustment and repeatable practice. The results align with the established importance of feeding management for feed utilization and organic-load control, while also supporting the expanding role of digitalization in aquaculture management (Joffre et al., 2022; Tacon & Metian, 2015).

Within Water Quality Control, Aeration and Water Circulation Effectiveness (0.349) and pH Stability Control (0.346) were nearly equal, followed by Dissolved Oxygen Management (0.182) and Ammonia and Nitrite Control (0.122). Aeration and circulation have direct operational relevance because they influence oxygen distribution and pond mixing. The relatively low global weights of water-quality sub-criteria arise mainly from the low parent-criterion weight; they should not be read as permission to relax minimum environmental limits. Water quality remains a non-negotiable operating constraint in intensive shrimp culture (Hargreaves, 1998).

Table 4. Consistency testing of AHP comparison matrices

Matrix	lambda max	CI	RI	CR	Decision
Main criteria	3.029	0.015	0.58	0.025	Accepted
Digital feeding	4.251	0.084	0.9	0.093	Accepted
Water quality	4.24	0.08	0.9	0.089	Accepted
Operational efficiency	4.243	0.081	0.9	0.09	Accepted

All four aggregated matrices met the CR <= 0.10 requirement (Table 4). The feeding and operational-efficiency matrices were close to the threshold but remained acceptable. This supports internal logical reliability, although consistency is not a substitute for external validation. The judgments are context-specific and represent a structured consensus among five experts rather than a statistically generalizable population estimate.

Managerial implications. The priority structure recommends a staged improvement program. First, management should strengthen labor capability through role clarity, targeted training, shift supervision, and measurable execution standards. Second, preventive maintenance should be formalized for aerators, pumps, feeders, generators, and sensors, with inspection intervals and downtime records. Third, energy consumption should be monitored without compromising oxygen and circulation requirements. Fourth, digital feeding investments should be tied to feeding-frequency control, reliable records, and clear decision rules. Throughout these improvements, water-quality monitoring and corrective thresholds must remain mandatory safeguards.

The model also demonstrates a useful boundary between priority and causality. AHP ranks perceived managerial importance; it does not prove that a 1% increase in one criterion causes a proportional increase in harvest productivity. Future research should test these priorities against farm-level outcomes such as feed conversion ratio, survival rate, average body weight, energy intensity, equipment downtime, and profitability across multiple farms and production cycles.

CONCLUSION

The AHP analysis identified Operational Efficiency as the first managerial priority supporting intensive shrimp-farm productivity (58.57%), ahead of Digital Feeding Management (33.73%) and Water Quality Control (7.70%). Labor Productivity, Equipment Maintenance Management, and Energy Utilization Efficiency were the three leading global

sub-criteria. Feeding Frequency led the digital-feeding group, while Aeration and Water Circulation Effectiveness narrowly led the water-quality group. All comparison matrices satisfied the CR <= 0.10 criterion. Farm managers should therefore prioritize workforce performance and equipment reliability, integrate digital feeding around disciplined operating decisions, and continue water-quality control as a mandatory biological safeguard. The findings are specific to one company and five experts and should be validated using multi-farm operational-performance data.

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Authors' Contributions

B.H.R.H.: conceptualization, methodology, investigation, data curation, formal analysis, visualization, writing - original draft, and writing - review and editing.

Conflict Of Interest

The author declares no commercial or financial relationships that could be construed as a potential conflict of interest.

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