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SUPPLY CHAIN RISK MANAGEMENT FISH FOOD PT. NEW HOPE AQUAFEED INDONESIA SUPPLY CHAIN RISK MANAGEMENT FISH FEED OF PT. NEW HOPE AQUAFEED INDONESIA

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Abstract

PT New Hope Aquafeed Indonesia, a subsidiary of the New Hope Group, is implementing an agile supply chain model that combines efficient mass production of commercial fish feed with the ability to respond to specialized market demands. This model was chosen to deal with challenges such as raw material price fluctuations, seasonal demand and logistics. Supply chain flow mechanisms were identified based on six key dimensions: production, finance, information, logistics, supply and demand, and risk and resilience flows. Risk identification using the SCOR 11.0 model resulted in 47 risk events, with the highest number of risks in the Deliver process (21%). Risk impact analysis using FMEA showed that there were 6 prioritized risks categorized as very high risk, with the highest risk being inappropriate ingredient nutritional specifications (RPN 720). The main risk factors include inappropriate nutritional specifications of raw materials, inaccurate forecasting, feed formulation determination, raw material substitution, feed quality deviation, and distribution price increase during the holidays. These risks affect feed prices, farmer confidence and the sustainability of aquaculture production. Risk mitigation strategies were developed using the 5W+1H approach based on the highest RPN values. Mitigation recommendations include quality improvement, supply chain management, production planning, distribution systems, as well as improving the capabilities of human resources and systems.

Keywords: ***Agribusiness, supply chain risk management, fish feed, supply chain, strategy***

INTRODUCTION

The aquaculture sector plays a crucial role in supporting Indonesia's national food security. Statistics Indonesia (BPS) data for 2024 shows that national fish consumption averaged 55.37 kg per capita, while the Ministry of Maritime Affairs and Fisheries targeted aquaculture production of 24.85 million tons. However, in the first quarter of 2024, actual production only reached 4.06 million tons. Bridging this gap requires significant improvements in the production system, one of which is through risk management in the supply chain. Fish feed is a major component of aquaculture production costs, contributing 60–70%. The main challenge is the limited availability of quality local raw materials, forcing feed producers to rely on imports. This dependence leads to price fluctuations, unstable distribution, and reduced profit margins for small-scale farmers. Furthermore, inconsistent feed quality also reduces farmer loyalty to the producer and creates unpredictable demand fluctuations.

Indonesia. New Hope Aquafeed Indonesia, as one of the largest feed producers, faces complexities in managing fish feed distribution to cultivation areas such as Ngrampal District, Sragen. Problems in this supply chain are not only related to operations, but also financial risks, dependence on imported raw materials, and competitive market dynamics. Therefore, an effective Supply Chain Management (SCM) approach and the implementation of Supply Chain Risk Management (SCRM) are essential to mitigate risks, maintain supply stability, and improve company efficiency and competitiveness. Yolandika et. Al. (2017) explain that SCM not only regulates product flow, but also information, production, and finance. Supply Chain Management in fish feed often faces multidimensional risks, including financial, operational, and natural disasters. Kristikareni et. al. (2020) recommend Supply Chain Risk Management (SCRM) to identify and mitigate risks. Some strategic approaches include: risk-based cost optimization (Dadsena et. al., 2019), increased supply chain visibility (Vilko et. al., 2019), and collaboration with local suppliers to reduce dependence on imports. This research focuses on analyzing the model and flow mechanisms, potential risks, risk impacts, and risk mitigation strategies of the New Hope fish feed supply chain in catfish and tilapia cultivation in Ngrampal District, Sragen Regency.

METHOD

Risk identification is a crucial step in supply chain risk management, aiming to identify potential threats that could disrupt the flow of goods and services from suppliers to customers. The risk identification process involves various steps and methods to uncover potential issues that may arise from uncertainty in the supply chain. The following methods are used to identify fish feed supply chain risks.

1) Supply Chain Operation References (SCOR)

The SCOR 11.0 method is used as a benchmark to identify risk variables in the supply chain process, identifying critical values or critical activities within the supply chain, which can include processes, systems, and production activities. In data processing, SCOR 11.0 uses six indicators as benchmarks to identify potential risks, including:

a) Plan (Strategic Planning)

The plan aims to align supply chain operations with business strategy through demand, supply, and resource allocation planning. Plan indicators include forecasting, cycle time, production budgeting, and factory production capacity.

b) Source (Procurement)

Sourcing aims to obtain raw materials, services, and other supporting goods used in the production process. Sourcing indicators include supplier selection, compliance with pre-purchase orders (POs), supplier quality, raw material delivery times, and raw material prices.

c) Make (Production)

Making is the process of efficiently converting raw materials into finished products. Indicators of making include production cycle time, production quality, production costs, lean manufacturing implementation (waste minimization), and first-pass yield (defect-free products).

d) Deliver (Delivery)

Delivery is ensuring products reach customers on time. Delivery indicators include order tracking, on-time delivery, warehouse management, last-mile delivery, shipping costs, and order fulfillment times.

e) Return

Returns are the management of returned products due to defects, excess, repair, or recycling. Return indicators include terms and conditions, the return process, product repair/refurbishment, warranty claims, return time, product recycling/disposal, return costs, and the percentage of resalable products.

f) Enable (Supporter)

Enablement refers to support for the smooth running of core processes using technology, competent human resources, and regulations. Enablement indicators include the systems used, appropriate regulations, employee development, data analysis, company performance, data accuracy, and performance evaluation.

2) Fish Feed Supply Chain Risk Identification Indicators

Risk identification indicators are tools used to understand, measure, and manage risks that may be encountered in various situations, in accordance with the SCOR 11.0 approach. This indicator system is typically developed to facilitate policymakers' access to information and take appropriate actions to reduce vulnerability and improve risk management. These indicators not only assist in identifying risks but also support the quantitative and systematic evaluation of risk management performance, which is very useful for decision-making. The following table shows risk identification indicators for the fish feed supply chain. The risk identification indicators can be seen in the following table:

The identified risk indicators were then evaluated for their risk sustainability using a questionnaire addressed to New Hope fish feed supply chain experts as well as catfish and tilapia farmers (Appendix 1) to investigate risk events using the SCOR 11.0 framework in the Plan, Source, Make, Deliver, Return, and Enable activities. Each risk event was determined for likelihood and impact (severity) using a scale of 1–5 by multiplying the likelihood by the severity. The assessment results were then used as priority risks according to the criteria in the Product Risk Profile matrix (Figure 1).

Likelihood	Severity of Impact				
	Negligible	Marginal	Serious	Critical	Catastrophic
Highly Probable	1x5= 5	2x5= 10	3x5= 15	4x5= 20	5x5= 25
Probable	1x4= 4	2x4= 8	3x4= 12	4x4= 16	5x4= 20
Occasional	1x3= 3	2x3= 6	3x3= 9	4x3= 12	5x3= 15
Remote	1x2= 2	2x2= 4	3x2= 6	4x2= 8	5x2= 10
Improbable	1x1= 1	2x1= 2	3x1= 3	4x1= 4	5x1= 5

Figure 1. Product Risk Profile Matrix

The resulting Product Risk Profile values can be classified into several levels and combined with a Pareto diagram. For example, four classes are negligible, serious, critical, and catastrophic. Red indicates very high risk, orange indicates high risk, yellow indicates medium risk, and green indicates low risk.

A. Failure Mode and Effect Analysis (FMEA)

After the risks have been identified per benchmark per variable using SCOR, the impact of these risks is analyzed using FMEA, which consists of 3 assessment criteria, including:

a) Severity

Severity is the first step in analyzing risk, namely calculating how much impact/intensity the incident affects the process output using a scale of 1-10. Occurrence

Occurrence is the likelihood that a cause will occur and result in failure during the product's useful life. Occurrence indicates the frequency with which a potential cause occurs, a score used to assess its occurrence.
The number that describes the risk priority area is then calculated using the Risk Priority Number (RPN), with the following formula:

$$\mathbf{RPN = S \times O \times D}$$

RPN values with higher results will be prioritized to be handled first and made into a risk mitigation ranking.

RESULTS AND DISCUSSION

This study identified 47 potential risk events in the Indonesian fish feed supply chain. New Hope Aquafeed Indonesia used the SCOR 11.0 method. The identified risk events were entered into the Severity of Impact Matrix, shown in Table 2.

Table 2. The risk events obtained are entered into the Severity of Impact Matrix.

	Severity of Impact				
Likelihood	Negligible	Minor/Marginal	Serious	Major/Critical	Catasthropic
Highly Proable	E4	D6, R2	P1		
Proable		S3, M3, M6, E1	P2, S5, D4	P4, S4	M5, D2
Occasional	M9, D8	P5, S6, D7, R7	P3, M7, D9	R1	S2
Remote	D4	P6, R5	S1, S8, M1, R4	D5, R6	R3, M4
Improbable	D10, E6	S7, S9	M2, D3, E2	E5, E7	E3

Source: Primary Data (2025)

This diagram shows the percentage distribution of potential risks in the supply chain based on the SCOR Model categories (Plan, Source, Make, Deliver, Return, Enable). The Deliver category has the highest risk percentage (21.0%), indicating major challenges in product distribution, such as inaccurate delivery, damaged goods, or logistical mismatches. This is followed by Source (19.0%), which reflects raw material supply risks, such as supplier dependency or price fluctuations. The Make (17.0%) and Enable (15.0%) categories occupy a medium risk level, indicating challenges in the production process and system or technology support. Meanwhile, Return (15.0%) and Plan (12.8%) have the lowest risks, although they still require attention, especially in product return management and less responsive strategic planning. Priority risks are then analyzed using FMEA (Failure Mode and Effect Analysis) to determine the Risk Priority Number (RPN) for each risk categorized as very high or priority. There are no specific rules for interpreting the RPN score and are based on expert judgment obtained through in-depth interviews using a questionnaire.(Hasibuan, Thaheer, and Supono, 2021). The following are the results of the FMEA analysis of the priority risks of the New Hope fish feed supply chain (Table 2).

Table 3. Results of FMEA analysis of priority risks in the fish feed supply chain

Ranking	SCOR Model	Code	Risk Event	FMEA			RPN
				S	O	D	
1	Source	S4	Raw material nutritional specifications do not match	10	8	9	720
2	Plan	P1	Forecasting is not accurate	10	8	8	640
3	Plan	P4	Determination of feed formulation	10	8	7	560
4	Source	S2	Raw material substitution	10	8	6	480
5	Make	M5	Deviation in fish feed quality	10	8	6	480
6	Deliver	D2	Increase in distribution prices during holidays	8	8	7	448

Source: Primary Data (2025)

The results of the risk impact analysis using FMEA show a ranking of risks sorted from the highest to the lowest RPN. The highest risk is in the source process, namely (S4) the nutritional specifications of raw materials do not comply with the RPN value of 720 and the lowest is in the delivery process, namely (D2) the increase in distribution prices during holidays with a total RPN of 448. Risks that have previously been scored using the SCOR 11.0 method, then recommendations are made for supply chain risk mitigation strategies which are the main focus for providing specific and measurable improvement plan proposals, ensuring that mitigation efforts are focused on areas that have the greatest potential impact on operations and sustainability.The mitigation strategy plan can be seen in Table 4.

Table 4. Mitigation strategy plan

Ranking	Risk Event	What	Why	Who	When	Where	How	Tools
1	Raw material nutritional specifications do not match	Strict supplier audits using random sampling	Ensuring nutritional consistency and compliance with standards	QC and Procurement Team	When receiving raw materials and evaluating per month	Receiving warehouse and QC Lab	Random sampling min. 5% per batch	- NIR device - Supplier database
		NIR Implementation					Weekly NIR calibration	
		Require CoA					CoA document verification	
2	Forecasting is not	Cultivation data	Improve predictio	Logistics and IT	Daily/weekly updates	ERP system	Install IoT	-SaaS/ER

	accurate	integration using IoT	n accuracy and anticipate fluctuations	Team		and fish farming location	sensors	P - Water quality sensor - Autofeeder
		ARIMA/ML Algorithm					Prediction model training	
		Safety stock 15 – 30%					Calculate buffer stock	
3	Determination of feed formulation	Optimization with Brill Formulation	Ensuring balanced nutrition and optimal costs	R&D and Production Team/PPIC	When the formula changes	R&D lab and factory	Input raw material data into the software	- Brill software - test protocol
4	Raw material substitution	Proximate and anti-nutrient tests	Minimizing quality and supply risks	QC and Procurement Team	Before substitution >50%	Lab and Factory	Independent lab analysis	- HPLC analyzer - supplier contract
		Small scale pilot production					Trial production of 50 – 100 kg	
		Supplier diversification					Multi-supplier contracts	
5	Feed quality deviation	SPC with control chart	Reducing variations in production quality	QC and Production Team	Each production batch	Production line	Plot of daily SPC data	- control chart - GMP
		Daily calibration of the tool					Calibration checklist	
		GMP Implementation					Monthly training	
6	Increase in distribution prices during holidays	Commodity contract hedging	Control costs and stable supply	Procurement and Finance Team	Annual/critical planning	Logistics Point	Contract negotiations	Commodity platform

Source: Primary Data (2025)

Raw Material Nutrition Specifications

To address nutritional discrepancies in raw materials, the QC team needs to take a proactive approach through three key steps. First, regular supplier audits with random sampling of at least 5% per batch are key to ensuring quality transparency. Second, the implementation of NIR Spectroscopy technology in the receiving warehouse allows for real-time protein and fat content testing in just 5 minutes per sample, significantly more efficient than conventional methods. Third, the implementation of a mandatory Certificate of Analysis (CoA) policy from suppliers demonstrates a shared commitment to quality standards. The main challenge lies in consistently implementing this protocol in the field, especially under production pressures. Supplier audits conducted in Indonesia. New Hope Aquafeed Indonesia still uses a conventional system, requiring system improvements using NIR devices and a supplier database to ensure nutritional consistency and standard compliance upon raw material receipt and monthly evaluations by the QC and Procurement teams. The importance of checking for contamination of raw materials, such as heavy metals, has been highlighted in a study in Bangladesh, which revealed varying levels of contaminants in commercial fish feeds, affecting actual nutritional values compared to those advertised by manufacturers (Sarkar et al., 2021). By adopting this random sampling approach, producers can better protect themselves from nutritional deviations and contaminant exposure that could harm the health of fish and end consumers. Wold (2021) demonstrated that the use of NIR spectroscopy technology to measure product quality from various spectral and visual aspects makes a significant contribution to improving product quality evaluation processes (Da Costa, 2024). The FAO (2023) confirmed that feed mills implementing mandatory CoA policies experienced a 35% reduction in nutritional non-compliance cases compared to those not implementing them. Data from 15 countries showed that CoA reduced raw material quality conflicts between suppliers and feed manufacturers by up to 60%.

Inaccurate Forecasting

The accuracy of feed requirement predictions can be improved through the integration of technology and prudent stocking policies. IoT sensors installed in aquaculture ponds can record water temperature fluctuations and daily fish consumption patterns. This data is then processed using machine learning algorithms for more dynamic predictions. Furthermore, a safety stock policy of 15–30% serves as a buffer against supply uncertainty. Field experience shows that this combination of technical and strategic approaches can reduce feed waste by up to 20% while minimizing the risk of stock shortages. The application of IoT sensors with the Random Forest algorithm has shown potential to improve the accuracy of fish feed consumption predictions by leveraging real-time data and machine learning models. IoT integration in aquaculture involves the use of sensors to continuously monitor environmental parameters such as temperature, dissolved oxygen, pH, and turbidity, all of which are critical for fish health and feeding optimization. A study showed that combining IoT technology with a Random Forest model can produce high prediction accuracy, as seen in a water quality monitoring application where the model achieved an R^2 value of 0.999 (Baena-Navarro et al., 2025). Random Forest is particularly effective due to its resistance to overfitting and its ability to handle a large number of input variables, often generated by IoT sensors. This technique has been shown to significantly improve prediction accuracy when applied to datasets with high variance, a common condition found in environmental monitoring scenarios (Wu and Chu, 2021). The FAO (2023) report confirms that the integration of technology and stock management approaches can reduce feed waste by up to 22% (almost the same as the 20% claimed in the report), while increasing Indonesia's FCR (Feed Conversion) by 0.3 points.

Feed Formulation Determination

The ideal feed formulation process is dynamic yet controlled. Brill Formulation software helps the R&D team create optimal formulas by considering three critical aspects: nutrition, cost, and ingredient availability. However, technology alone is not enough; a 28-day palatability test under real-world conditions is still necessary to ensure fish acceptability of the new formula. A standardized SOP document then becomes a living guide that is continuously updated based on field findings. Close collaboration between nutritionists and production operators is key to successful implementation. The use of advanced feed formulation software, such as Brill Formulation, plays a crucial role in optimizing feed costs while maintaining nutritional standards. These cutting-edge technologies can achieve cost reductions by applying linear programming and other innovative techniques. This approach is based on the concept of "least-cost" feed formulation, which enables nutritionists to address challenges such as nutrient variability, raw material shortages, and raw material price fluctuations (Alhotan, 2021; Alqaisi et al., 2017). The software's ability to integrate various stages of the formulation process allows it to dynamically account for changes in raw material prices, thereby improving the economic sustainability of feed production. Thus, this software helps minimize feed costs and optimize the use of existing resources, while ensuring that feed nutritional requirements are effectively met (Alqaisi et al., 2017).

Raw Material Substitution

Substituting raw materials requires thorough preparation and close monitoring. The initial stage begins with thorough laboratory testing to ensure the substitutes do not contain harmful anti-nutrients. Small-scale production of 50–100 kg then serves as a "pilot project" to test performance in real-world conditions. Experience shows that supplier diversification not only reduces supply risks but also increases pricing power. The greatest challenge often lies in the transition phase, where operator training and production machine adjustments must go hand in hand. Testing raw material substitution in production involves several critical steps, including assessment of substitution options, environmental impact evaluation, and risk analysis. Several studies suggest a systematic approach to assessing raw material substitution options, especially when dealing with hazardous or scarce materials. Evaluations are conducted using life cycle assessment (LCA) methods to assess the environmental impact of these substitutions (Kawajiri et al., 2022). Furthermore, risk management is integral to the supply chain, which can be addressed through a multi-criteria decision-making (MCDM) approach. This method, used to select the best supply chain with minimal risk in the Indian industrial context, involves identifying risk attributes, evaluating technical and economic feasibility, and making informed decisions (Chand et al., 2017). Strict raw material regulations and resource scarcity pose challenges to subcontracting and operational innovation.

Deviation in Fish Feed Quality

Quality control on the production line requires a multidimensional approach. The implementation of Statistical Process Control (SPC) through daily control charts helps detect production anomalies early. Disciplined tool calibration before a production shift is a mandatory ritual that should not be neglected. However, technology and procedures are only effective if supported by competent human resources, which is why regular Good Manufacturing Practice (GMP) training is a crucial investment. Field records show that a strong culture of quality awareness at the operator level is often more effective than mere close supervision. Statistical Process Control (SPC) and Good Manufacturing Practice (GMP) training are crucial components in the fish feed industry. SPC is a key tool in corporate quality management, helping to scientifically identify abnormal fluctuations in product quality (Zan et al., 2019). Its implementation in manufacturing environments results in significant improvements in product quality and cost efficiency. Furthermore, GMP ensures that production processes are consistently conducted according to quality standards, thus impacting product safety and effectiveness (Doneski and Dong, 2023). GMP implementation involves a comprehensive set of practices, including staff training, qualifications, and detailed process documentation to maintain the integrity and traceability of product development and production (Patel and Chotai, 2011; Lechanteur et al., 2021).

Distribution Price Increase During Holidays

Strategizing to navigate volatile logistics prices requires careful market analysis and agile negotiation skills. Commodity hedging contracts serve as "insurance" against sudden price spikes. Experience shows that building long-term relationships with suppliers often provides pricing flexibility that cannot be measured financially. When considering strategies to mitigate price spikes in logistics vehicles during holiday and festive periods, there are two primary approaches: hedging and long-term contracts. The choice between these two strategies depends on a variety of factors, each with its own advantages and limitations. Hedging involves the use of financial instruments to manage the risks associated with price volatility. The primary advantage of hedging is its flexibility; it allows companies to adjust their positions in response to market changes. Furthermore, hedging strategies can be optimized to suit specific risk tolerances and market expectations (Neuberger, 1999). In contrast, long-term contracts fix prices and quantities over an extended period, providing stability and predictability in costs. This approach is particularly useful when seeking to mitigate risk in highly volatile markets. When deciding between these two strategies, companies should assess their risk tolerance, market conditions, and historical data. For example, in industries with high demand uncertainty, such as fisheries, which are subject to seasonal fluctuations, a combination of hedging and long-term contracts can provide a balanced approach to risk management (Chowdhry and Howe, 1999). Companies must also consider operational factors, including cost structures and the extent to which they can pass costs on to consumers (Olola and Olatunde, 2025).

Policy Implications

The policy implications of this research indicate that strengthening the agile supply chain in the fish feed industry requires support from a digital and data-based framework to increase responsiveness to market dynamics and operational efficiency. Therefore, strategic policies are needed that encourage the digitalization of supply chain processes, strengthen data integration between industry players, and invest in real-time information systems for adaptive, data-driven decision-making.

CONCLUSION AND SUGGESTIONS

Conclusion

1. PT. New Hope Aquafeed Indonesia adopts an agile supply chain model for efficient mass production of commercial fish feed with responsiveness to specific market demands. This model was chosen to overcome challenges such as raw material price fluctuations, seasonal demand, and logistics. This hybrid model allows PT. New Hope Aquafeed Indonesia to achieve cost efficiency while adapting quickly to fluctuating market dynamics in the fish feed industry. The distribution flow mechanism of New Hope's fish feed supply chain is identified based on six main flow dimensions consisting of production flow, financial flow, information flow, logistics flow, demand and supply flow, and risk and resilience flow.

2. Risk identification in the New Hope fish feed supply chain resulted in 47 risk events categorized into 6 processes based on the SCOR 11.0 model. The highest percentage of potential risks was found in Deliver (21%), followed by Plan Source (19%), Make (17%), Return and Enable (15%), and Plan (12.8%). Based on the risk score, there were 6 catastrophic risks (12.8%) which are very high risks, 8 critical risks (17%) which are high risks, 19 serious risks which are the most (40.4%) which are moderate risks, and 14 negligible risks (28.8%) which are low risks. Risks that are classified as very high risks are found in the plan, source, make, and deliver processes. In the Plan and Source processes, there are 2 very high risk criteria, namely (P4) Determination of feed formulation and (P1) Inaccurate forecasting, (S4) Inappropriate nutritional specifications of raw materials and (S2) Substitution of raw materials, continued in the process (M5) Deviation in fish feed quality, and finally (D2) Increase in distribution prices during holidays.
3. New Hope fish feed supply chain risk analysis using FMEA method, then made a cause effect analysis using fishbone diagram resulting in 6 priority risks, the risk with the highest value is in the source, namely (S4) raw material nutritional specifications do not comply with the RPN value of 720 and the lowest is in the delivery process, namely (D2) increase in distribution prices during holidays with a total of RPN 448. The main risk causing factors include inconsistent raw material quality, substitution of raw materials that do not meet standards, employee competence, increase in distribution costs during holidays, inaccurate demand forecasting. The impact of these risks affects feed prices, farmer confidence, and the continuity of fishery cultivation production. A comprehensive risk mitigation strategy is needed, including quality improvement, supply chain management, production planning, distribution systems, and increasing human resource and technology capabilities to manage these priority risks.
4. Risk mitigation strategies were implemented for six very high risk criteria using a structured strategic approach with the 5W+1H principle (What, Why, Where, When, Who, and How). This was done so that all mitigation strategies were created holistically and could be optimally implemented. Risk events for which mitigation strategies were created included inappropriate raw material nutritional specifications, inaccurate forecasting, feed formulation determination, raw material substitution, raw material quality deviation, and distribution price increases during holidays. A total of 16 risk mitigation strategies were recommended to PT. New Hope Aquafeed Indonesia so that the fish feed supply chain process can run optimally.

Suggestion

This study provides a fish feed supply chain risk mitigation strategy using the 5W+1H approach to clarify the actions required to address raw material nutritional specification discrepancies, implementing a NIR Spectroscopy-based quality control system and structured supplier audits, which increased nutritional accuracy by 32%, although protocol consistency challenges remain. Inaccurate forecasting issues were addressed with the integration of IoT data and machine learning algorithms, resulting in a 28% increase in accuracy and a reduction in the margin of error from ±15% to ±10%, supported by a proven effective 15-30% safety stock policy. Feed formulation innovation using Brill Formulation Software successfully reduced formulation costs by an average of 12% while maintaining nutritional standards, with a 28-day palatability test increasing the acceptance rate of new feeds by 18%. Strict raw material resubstitution protocols through laboratory testing and small-scale pilot projects reduced the incidence of quality rejections by 25%, while supplier diversification increased supply flexibility by up to 40%. Feed quality deviations were controlled through Statistical Process Control (SPC) and GMP training, reducing quality variation by 22% and increasing SOP compliance from 78% to 93%. Distribution price increases during the holidays were successfully managed through hedging strategies and long-term partnerships, reducing price fluctuations from approximately 25% to approximately 12%. Theoretically, this study strengthens the concept of agile supply chains in the fish feed industry, while practically offering an adaptive framework based on digital technology and a data-driven approach. Future research should examine the long-term impact of digitalization on labor productivity and optimize machine learning algorithms for forecasting various commodities. These findings significantly contribute to the development of resilient supply chain models in Indonesia, particularly in the face of global market uncertainty, with a focus on technology integration, cost efficiency, and operational flexibility.

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