

Supply Chain Vulnerability Analysis for Improving Resilience in Aquaculture Technology Company

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Abstract— The aquaculture industry plays an important role in supporting food security, economic development, and environmental sustainability. However, aquaculture technology companies continue to face various supply chain vulnerabilities because they depend on imported components, multiple suppliers, and complex operational activities. Previous studies have investigated supply chain resilience and sustainability in agricultural industries. However, limited research has examined the main vulnerabilities affecting supply chain performance in aquaculture technology companies and developed mitigation strategies to strengthen resilience under uncertain business conditions. Therefore, this research aims to identify the main vulnerabilities affecting the supply chain and formulate appropriate mitigation strategies to improve supply chain resilience. A qualitative descriptive approach was adopted through supply chain mapping, vulnerability analysis, Political, Economic, Social, and Technological (PEST) analysis, and mitigation strategy development. The findings indicate that procurement and logistics represent the most critical sources of supply chain vulnerability due to delays in imported components, supplier dependency, limited warehouse capacity, and inaccurate delivery timing. The proposed mitigation strategies are estimated to reduce overall supply chain vulnerability by 79.45%. This research proposes an integrated framework for identifying supply chain vulnerabilities and developing mitigation strategies to improve supply chain resilience in aquaculture technology companies.

Keywords— Industrial Engineering, PEST Analysis, Supply Chain Resilience, Vulnerability Analysis.

I. INTRODUCTION

The aquaculture industry plays an important role in supporting food security, economic development, employment generation, and environmental sustainability. As one of the world's largest maritime countries, Indonesia has considerable potential in the aquaculture industry. Along with the increasing demand for seafood products, the aquaculture industry continues to grow and becomes one of the strategic sectors that contribute to the national economy [1]. However, despite its considerable potential, the aquaculture industry continues to face many operational challenges that affect productivity and business sustainability. Traditional aquaculture systems still depend on conventional energy consumption, manual pond monitoring, inconsistent water quality management, and inefficient operational activities,

resulting in high operational costs and unstable production performance [2]. Previous studies also reported that inefficient aeration systems, fluctuating dissolved oxygen levels, and poor environmental monitoring remain the major problems affecting aquaculture productivity and environmental sustainability [3].

Currently, many technology-based aquaculture companies have implemented renewable energy systems, Internet of Things (IoT)-based monitoring, and smart farming technologies to improve operational performance. The implementation of these technologies helps reduce energy consumption, improve water quality management, and increase production efficiency. However, the successful implementation of these technologies is not only determined by technological innovation but also by the performance of the supply chain system. Technology-based aquaculture companies require electronic components, IoT sensors, renewable energy equipment, and mechanical parts supplied by local and international suppliers. The supply chain also involves manufacturing, warehousing, distribution, installation, and after-sales services before the products reach the customers. Disruption in one supply chain activity can affect other activities and reduce operational performance [4]. Therefore, maintaining supply chain resilience becomes important to improve operational continuity and business sustainability [5]. Preliminary observations identified several vulnerabilities in the supply chain of the technology-based aquaculture company. The main vulnerabilities include delays in imported components, dependency on single suppliers, limited warehouse capacity, and inaccurate delivery scheduling.

Previous research has been conducted on supply chain resilience [6], sustainability, and risk management in agricultural and aquaculture industries [7]. Previous studies also discussed biological risks [8], environmental sustainability, production efficiency, and market uncertainty in the aquaculture industry [9]. However, limited research discusses supply chain vulnerabilities in technology-based aquaculture companies, especially in developing countries. Existing studies also have not integrated PEST (Political, Economic, Social, Technological) analysis [10], vulnerability analysis [11], and sustainability-oriented mitigation strategies [12] into one assessment framework

Recent studies show that global supply chains continue to face disruptions after the COVID-19 pandemic due to geopolitical tensions, transportation problems, and other global events [13]. Political factors can affect international sourcing, trade, and customs processes, while economic factors such as exchange rate changes and higher logistics costs can increase procurement and transportation costs [14]. These factors are particularly important for companies that depend on imported components because they can affect material availability, costs, and production planning. However, limited studies have examined how these external Political and Economic factors are linked to specific supply chain vulnerabilities in technology-based aquaculture companies. Identifying these vulnerabilities is important because it helps determine which supply chain activities are most exposed to disruption and require priority mitigation.

Therefore, this study addresses the identified gap by integrating PEST analysis, critical node assessment, and supply chain vulnerability analysis to identify the main vulnerabilities and their influencing factors in an Indonesian technology-based aquaculture company. Based on the identified vulnerabilities, appropriate mitigation strategies are formulated to improve supply chain resilience. The proposed framework is expected to help technology-based aquaculture companies improve supply chain resilience while supporting Sustainable Development Goals (SDG) 7 [15], SDG 9 [16], and SDG 12 [17].

II. METHOD

This research uses a qualitative descriptive approach to identify supply chain vulnerabilities in an Indonesian aquaculture technology company. The qualitative approach is selected because it can provide a better understanding of the factors affecting supply chain vulnerabilities under uncertain business conditions. The research methodology consists of four stages, namely supply chain mapping, vulnerability identification, external environment analysis, and mitigation strategy development. Each stage is conducted sequentially because the results obtained from the previous stage become the basis for the next stage.

A. Supply Chain Mapping

The first stage is supply chain mapping. The purpose of this stage is to identify the overall supply chain activities of the company and determine the relationship between each activity. Supply chain mapping is conducted to provide an overview of the material flow and information flow from suppliers to customers [18]. The supply chain begins with procurement activities from local and international suppliers, followed by import and customs clearance, inbound logistics, production and assembly, quality control, warehousing, distribution, and product delivery to customers. Every activity in the supply chain has different responsibilities and is interconnected with other activities. Therefore, disruption occurring in one activity has the potential to affect other activities and reduce the overall supply chain performance.

B. Vulnerability Identification

After the supply chain mapping is completed, the next stage is vulnerability identification [19]. The purpose of this stage is to identify the main vulnerabilities occurring in each supply chain activity and determine the vulnerabilities that have the greatest impact on supply chain performance [20]. At this stage, data are collected through semi-structured interviews, direct observation, and company documents. Five

respondents representing procurement, production, logistics, sales, and technical services are selected as key informants. All respondents hold at least a managerial position and have more than five years of experience in their respective functions, ensuring that they have sufficient knowledge of the supply chain processes. After all vulnerabilities are identified, each vulnerability is evaluated based on its impact on operational activities. The results of this stage are used to determine the main vulnerabilities that require priority attention in the next stage of the research.

C. External Environment Analysis

The next stage is external environment analysis using the Political, Economic, Social, and Technological (PEST) framework as shown in Fig. 1.

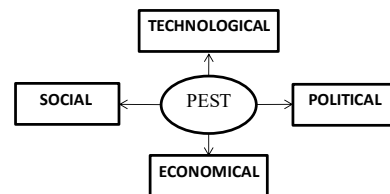


Fig. 1. PEST framework

The purpose of this stage is to identify external factors affecting supply chain vulnerabilities [21]. Political factors include import regulations, customs policies, and government support for renewable energy technology. Economic factors include exchange rate fluctuations, inflation, and increasing logistics costs that affect procurement and distribution activities. Social factors include digital literacy, technology acceptance, and awareness of sustainable aquaculture practices among customers. Technological factors include dependency on imported components, technological infrastructure, and the availability of digital systems supporting operational activities. At this stage, every external factor is analyzed to determine its potential impact on the supply chain. The results of this analysis are used to identify external conditions that may increase supply chain vulnerabilities and support the development of appropriate mitigation strategies.

D. Mitigation Strategy Development

After the main vulnerabilities and external factors are identified, the final stage is mitigation strategy development [22]. The purpose of this stage is to formulate strategies that can reduce supply chain vulnerabilities and improve supply chain resilience. The proposed mitigation strategies are developed based on the results of supply chain mapping, vulnerability identification, and external environment analysis. Each mitigation strategy is designed to address the main causes of vulnerabilities occurring in the supply chain. The proposed strategies include supplier diversification to reduce dependency on a single supplier [23], safety stock implementation to minimize material shortages [24], digital inventory systems to increase inventory visibility through Internet of Things (IoT) [25]. The proposed mitigation strategies are expected to reduce the impact of supply chain disruptions, improve operational continuity, and support the development of a more resilient and sustainable supply chain.

III. RESULTS & DISCUSSION

A. Supply Chain Mapping

The first stage of this research is supply chain mapping. The purpose of this stage is to identify the overall supply chain activities and determine the relationship between each activity. Supply chain mapping is conducted to provide an overview of the movement of materials and information from suppliers to customers. By knowing the overall supply chain activities, the critical nodes that have the greatest influence on supply chain performance can be identified. Fig. 2 shows the supply chain activities of the aquaculture technology company. The supply chain begins with procurement activities from local and international suppliers that provide electronic components, IoT sensors, printed circuit boards (PCB), renewable energy equipment, and mechanical parts. After the procurement process is completed, imported materials pass through customs clearance and inbound logistics before entering the production and assembly process. The finished products are then inspected through the quality control process before being stored in the warehouse. The products are distributed to distributors and customers before reaching shrimp and fish farmers as the final users.

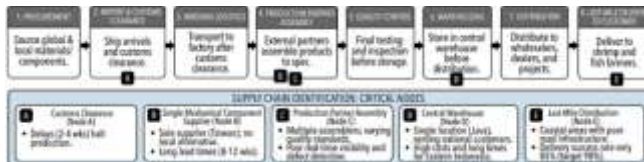


Fig. 2. Supply chain mapping

The results of the supply chain mapping show that there are five critical nodes that have the potential to affect the overall supply chain performance, namely import customs clearance (Node A), single mechanical component supplier (Node B), production partner assembly (Node C), central warehouse (Node D), and last-mile distribution (Node E). These critical nodes are identified because disruptions occurring in these activities can affect other supply chain activities and reduce operational performance.

Node A represents the import customs clearance process. Most electronic components and IoT equipment are imported from overseas suppliers. Therefore, delays during customs clearance have the potential to delay material availability and affect the production schedule. The results of the observation indicate that customs clearance may require two to four weeks before the materials can be delivered to the production partner. This condition causes procurement activities to become one of the most important activities affecting supply chain performance. Node B represents the procurement of critical mechanical components supplied by a single supplier located in Taiwan. The lead time for these components ranges from eight to twelve weeks, and currently there are no local suppliers providing equivalent specifications. Therefore, the company has a high dependency on one supplier. If the supplier experiences production or transportation problems, the company also experiences delays in the production process because the required components cannot be substituted by other suppliers. Node C represents the production and assembly activities conducted by external manufacturing partners. The company currently collaborates with several production partners to assemble the final products. However, differences in production capability and quality control among production partners may affect product quality and production lead time. In addition, production monitoring is still limited,

making it difficult to identify production problems at an early stage. Node D represents the central warehouse used to store finished products before distribution. Currently, warehouse activities are concentrated in one location, resulting in longer delivery distances to several regions in Indonesia. This condition increases logistics costs and delivery time, especially for customers located outside Java. Meanwhile, Node E represents the last-mile distribution process. Distribution activities are highly influenced by transportation infrastructure and geographical conditions, particularly in coastal and remote areas. As a result, delivery performance does not always achieve the company's target because transportation activities depend on external conditions that cannot be fully controlled.

Based on the supply chain mapping, it can be seen that the five critical nodes are interconnected. Delays occurring during procurement activities affect production, warehousing, and distribution activities. Likewise, warehouse limitations affect delivery performance and customer satisfaction. Therefore, identifying the critical nodes becomes important because it helps determine which supply chain activities require priority improvement. The results of this stage are used as the basis for vulnerability identification and external environment analysis in the following stages.

B. Vulnerability Identification

After the supply chain mapping is completed, the next stage is vulnerability identification. The purpose of this stage is to identify the main vulnerabilities occurring in each supply chain activity and determine those with the greatest impact on supply chain performance. The identified vulnerabilities are evaluated using the FMEA 1–10 scale for Occurrence (O), Severity (S), and Detection (D). Each respondent scores the vulnerabilities individually based on the frequency of the identified problem, its effect on supply chain activities, and the ability to detect the problem before it affects operations. Occurrence is scored from 1 (very unlikely) to 10 (very frequent), Severity from 1 (minor effect) to 10 (severe effect on operations), and Detection from 1 (easily detected before impact) to 10 (very difficult to detect before impact). The scores from the five respondents are given equal weight and averaged to obtain the final O, S, and D scores. The RPN is calculated as $O \times S \times D$ and used to rank the identified

TABLE I. VULNERABILITY ASSESSMENT

Risk Number	Risk Category	Risk Description	O	S	D	RPN
1	Purchase	Delayed supply of imported components	8	9	7	504
2	Warehousing	Limited warehouse capacity & coverage	8	8	7	448
3	Logistics	Inaccurate delivery timing	8	8	7	448
4	Purchase	Single-supplier dependency	9	8	6	432
5	Sales	Slow adoption by farmers	7	8	6	336
6	Warehousing	Excess inventory of obsolete products	6	8	6	288
7	Sales	Limited after-sales service in remote areas	6	8	6	288
8	Manufacturing	Shortage of trained technicians	7	7	6	294
9	Logistics	High logistics cost per unit	7	7	6	294
10	Purchase	Price fluctuations	7	7	6	294

vulnerabilities. The results are presented in Table I. while the overall distribution of supply chain vulnerabilities is presented in Fig. 3. Based on Table I, delayed supply of imported components has the highest RPN of 504, with $O = 8$, $S = 9$, and $D = 7$. This result indicates that imported components are a major vulnerability affecting supply chain performance. The company depends on overseas suppliers for electronic components, IoT devices, and mechanical parts. Delays in international transportation and customs clearance can affect material availability and the production schedule. Since these components cannot be easily replaced by local suppliers, this vulnerability requires priority improvement availability and postpone the production schedule. Since these components cannot be easily replaced by local suppliers, procurement activities become one of the most important supply chain activities that require priority improvement.

The second highest vulnerability is limited warehouse capacity and coverage, with a total score of 448. Currently, the company stores finished products in one central warehouse before distributing them to customers located throughout Indonesia. This condition increases delivery distance, transportation cost, and delivery time, especially for customers located outside Java. The next vulnerability is inaccurate delivery timing, which also obtains a total score of 448. Delivery activities are highly affected by transportation infrastructure, weather conditions, and geographical characteristics of Indonesia as an archipelagic country. These conditions make it difficult for the company to maintain consistent delivery performance, particularly for customers located in coastal and remote areas. Delays in product delivery reduce customer satisfaction and affect the overall service level provided by the company. Single-supplier dependency becomes the fourth highest vulnerability with a total score of 432. The company currently depends on one supplier for several critical mechanical components. This condition increases supply chain vulnerability because any disruption experienced by the supplier will directly affect procurement activities and production schedules. In addition, the long procurement lead time makes it difficult for the company to quickly replace the supplier whenever disruptions occur. Several other vulnerabilities are also identified during the assessment process, including slow technology adoption by farmers, shortage of trained technicians, high logistics costs, excess inventory of obsolete products, and limited after-sales services in remote areas. Although these vulnerabilities obtain lower assessment scores compared with procurement and logistics activities, they still affect the overall operational performance of the company. These vulnerabilities should also receive attention to improve supply chain performance and customer satisfaction.

Fig. 3 show the distribution of vulnerabilities according to their occurrence, severity, and detection levels. The figure indicates that procurement and logistics activities dominate the high-risk area compared with manufacturing and sales activities. Most manufacturing vulnerabilities have relatively lower assessment scores because the company has implemented quality control procedures during production activities. These procedures help identify production problems before the products are delivered to customers.

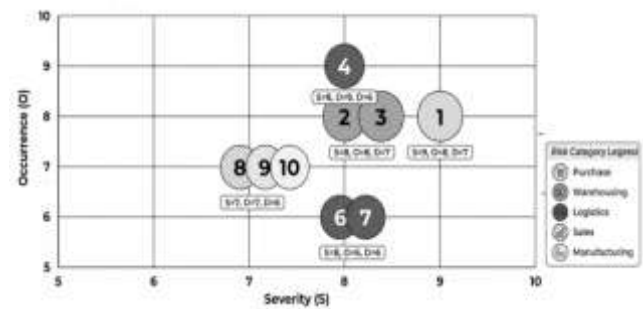


Fig. 3. Vulnerability risk mapping

On the other hand, procurement and logistics activities are more difficult to control because they depend on external parties, including international suppliers, customs authorities, transportation providers, and distribution partners. The results of this stage indicate that procurement, warehousing, and logistics become the three supply chain activities with the greatest potential to affect operational performance. Delays occurring in procurement activities also affect production, warehousing, and product distribution. Likewise, warehouse limitations reduce inventory flexibility and increase logistics costs, while delivery delays reduce customer satisfaction and service performance. Therefore, these vulnerabilities become the main priority for the next stage of the research to determine appropriate mitigation strategies and improve overall supply chain resilience.

C. External Environment Analysis

After the vulnerability identification is completed, the next stage is external environment analysis using the Political, Economic, Social, and Technological (PEST) framework. The purpose of this analysis is to identify the external factors that affect supply chain vulnerabilities and determine which factors have the greatest influence on the company's operational activities. Table II defines the numerical thresholds used to classify each PEST category based on its average score and number of High factors.

TABLE II. RISK CATEGORY

Category Risk Level	Numerical Condition
Low	Average score <1.50 AND number of high factors = 0
Moderate	Average score <2.00 AND number of high factors ≤ 1
High	Average score ≥ 2.00 OR number of high factors ≥ 2

Using these criteria, Table III presents the assessment results for each PEST category. Each factor is scored as Low (1), Moderate (2), or High (3), where Low indicates little effect, Moderate indicates a noticeable effect, and High indicates a strong effect on supply chain performance. The Economic factor has the highest average score of 2.00. The final risk level is determined by the average score and number of High factors: Low (<1.50 with no High factor), Moderate (<2.00 with no more than one High factor), and High (≥ 2.00 or at least two High factors). Based on these criteria, Political (1.83), Social (1.67), and Technological (1.83) are classified as Moderate, while Economic (2.00) is classified as High. This finding is consistent with recent studies showing that exchange rate changes, transportation costs, and global disruptions can affect sourcing and logistics activities [7]. In this study, these economic pressures (2.00) are particularly relevant because the company depends on imported electronic components and mechanical parts, making procurement costs

and production planning sensitive to exchange rate fluctuations, logistics costs, and raw material price changes. The Political factor obtains an average score of 1.83 and is categorized as a moderate risk. Political factors include import regulations, customs procedures, government policies, and trade regulations that influence procurement activities.

Although government policies supporting renewable energy provide opportunities for business development, changes in import regulations and customs procedures may increase procurement lead time and delay material availability.

TABLE III. PEST SCORING

Category	Original Factors	Risk Level	Risk score	Avg Score	Number "High" Case	Conclusion
POLITICAL	Import facilitation policies	Low	1.00	1.83	1.00	MODERATE
	Government subsidies	Low	1.00			
	Regulatory stability	Moderate	2.00			
	Trade policy shifts	Moderate	2.00			
	Domestic content rules	Moderate	2.00			
ECONOMIC	Political instability	High	3.00	2.00	2.00	HIGH
	IDR depreciation risk	High	3.00			
	Global logistics cost rise	High	3.00			
	Market growth in RE sector	Low	1.00			
	Input cost volatility	Moderate	2.00			
	FX exposure in contracts	Moderate	2.00			
	Interest rate fluctuations	Low	1.00			
SOCIAL	Farmer digital literacy gap	Moderate	2.00	1.67	-	MODERATE
	Slow IoT adoption	Moderate	2.00			
	Awareness campaign gaps	Low	1.00			
	Skill gap in maintenance	Moderate	2.00			
	Rural connectivity issues	Moderate	2.00			
TECHNOLOGICAL	Labor availability	Low	1.00	1.83	1.00	MODERATE
	R&D stagnation	Moderate	2.00			
	No local component manufacturers	High	3.00			
	IoT enabler adoption slow	Low	1.00			
	Supplier dependency	Moderate	2.00			
	After-sales service gaps	Moderate	2.00			
	Cyber security vulnerabilities	Low	1.00			

Scoring: Low=1. Moderate=2. High=3

The Social factor also has an average score of 1.67 and is categorized as a moderate risk. The assessment indicates that digital literacy, technology acceptance, and technical capability among farmers continue to influence the implementation of aquaculture technology. Some customers still require technical assistance before implementing renewable energy and Internet of Things (IoT)-based systems. In addition, limited technical knowledge and geographical conditions make after-sales services more difficult, particularly in remote areas.

The Technological factor obtains an average score of 1.83 and is also categorized as a moderate risk. One of the main findings is the high dependency on imported electronic components because domestic suppliers with similar specifications are still limited. This condition increases procurement lead time and reduces supply chain flexibility whenever supply disruptions occur. Other technological factors include the availability of digital infrastructure, supplier capability, and cyber security, which also influence operational performance. To provide a better understanding of the overall external environment affecting supply chain performance, the results of the PEST analysis are summarized into a PEST dashboard, as shown in Fig. 4, the dashboard provides an overview of the external factors affecting supply chain vulnerabilities and summarizes the overall risk level of each PEST category.

It helps management understand the current business environment, identify the dominant sources of risk, and determine priority mitigation actions. The dashboard can be accessed and reviewed monthly by the General Manager as part of the supply chain evaluation process.



Fig. 4. PEST Dashboard

By continuously monitoring changes in Political, Economic, Social, and Technological factors, the company can formulate appropriate mitigation strategies before external risks significantly affect operational performance. Therefore, the PEST dashboard serves as a decision-support tool to strengthen supply chain resilience under uncertain business conditions. The findings presented in the PEST dashboard also provide a better understanding of the external factors influencing the vulnerabilities identified in the previous stage. The results indicate that the main vulnerabilities occurring in procurement and logistics activities are strongly affected by Economic and Technological factors. Overall, the PEST analysis indicates that the company operates under uncertain external business conditions. By identifying the Political,

Economic, Social, and Technological factors affecting supply chain performance, the company can better understand the external conditions influencing operational activities and prioritize the most significant sources of risk. The results of this stage are subsequently used as the basis for developing mitigation strategies that reduce supply chain vulnerabilities and improve long-term supply chain resilience.

D. Mitigation Strategy Development

After the main vulnerabilities and external factors are identified, the final stage is mitigation strategy development. The purpose of this stage is to formulate strategies that can reduce supply chain vulnerabilities and improve supply chain resilience. The proposed mitigation strategies are developed based on the results of supply chain mapping, vulnerability identification, and external environment analysis. The current supply chain condition is summarized in Table IV.

TABLE IV. CURRENT-STATE (AS-IS) SUPPLY CHAIN RISK

Risk Category	Key Risk	As-Is Baseline				Pest As-Is		Mitigation Actions
		O	S	D	RPN	Category	Score	
Procurement /Purchased (Critical Node A & B)	Delayed supply of imported components	8	9	7	504	Economic/ Technological /Political	HIGH/ MODERATE/ MODERATE	• Dual sourcing (local + regional suppliers) • Safety stock buffer • Supplier diversification to reduce import dependency
Manufacturing	Technician shortages & assembly errors	7	7	6	294	Technological	MODERATE	• Annual technician certification program • QA digital standardization system
Warehousing & Inventory	Limited warehouse capacity & stock imbalance	8	8	7	448	Economic	HIGH	• Regional hubs (Surabaya, Makassar, Medan) • Real-time inventory system (barcode + cloud)
Distribution & Logistics	Inaccurate delivery timing / last-mile delays	8	8	7	448	Economic	HIGH	• IoT-based remote monitoring • Demand forecasting improvement
Market Adoption (Secondary Risk)	Slow farmer adoption	7	8	6	336	Social	MODERATE	• Training workshops + demo farms • Digital onboarding modules

TABLE V. FUTURE-STATE (TO-BE) SUPPLY CHAIN RISK

Risk Category	Key Risk	To-Be Baseline				Pest to be		Mitigation Actions
		O	S	D	RPN	Category	Score	
Procurement /Purchased (Critical Node A & B)	Delayed supply of imported components	4	9	4	144	Economic/ Technological /Political	MODERATE/ MODERATE/ MODERATE	• Dual sourcing (local + regional suppliers) • Safety stock buffer • Supplier diversification to reduce import dependency
Manufacturing	Technician shortages & assembly errors	3	7	6	126	Technological	MODERATE	• Annual technician certification program • QA digital standardization system
Warehousing & Inventory	Limited warehouse capacity & stock imbalance	4	8	3	96	Economic	MODERATE	• Regional hubs (Surabaya, Makassar, Medan) • Real-time inventory system (barcode + cloud)
Distribution & Logistics	Inaccurate delivery timing / last-mile delays	4	8	4	128	Economic	MODERATE	• IoT-based remote monitoring • Demand forecasting improvement
Market Adoption (Secondary Risk)	Slow farmer adoption	3	8	4	96	Social	LOW	• Training workshops • Digital onboarding modules

In contrast, the estimated supply chain condition after the implementation of the proposed mitigation strategies is presented in Table V. Based on Table IV, procurement activities obtain the highest vulnerability level among all supply chain activities, with delayed supply of imported components having the highest RPN (504). This finding is consistent with previous supply chain resilience studies, which identify supplier dependency, sourcing risk, and upstream disruptions as major sources of supply chain vulnerability [23]. In this study, the risk is mainly related to dependence on imported components, exchange rate changes,

import regulations, customs clearance, and international logistics conditions. Therefore, supplier diversification, safety stock for critical components, and procurement monitoring are proposed to reduce supply disruption and improve supply continuity. Distribution and logistics and warehousing and inventory activities also obtain a high vulnerability score (RPN = 448). Previous studies have similarly identified transportation and warehousing as important factors in supply chain resilience because delays and limited capacity can interrupt material and product flows [26]. In the present study,

TABLE VI. SIMULATED RISK REDUCTION PERCENTAGE

Risk Category	RPN (As-Is)	RPN (To-Be)	Risk Reduction (%)
Warehousing & Inventory	448	96	78.57
Procurement /Purchased	504	144	71.43
Distribution & Logistics	448	128	71.43
Market Adoption	336	96	71.43
Manufacturing	294	126	57.14
All Risk Category	2030	566	70.94

these risks are influenced by transportation conditions, geographical factors, and increasing logistics costs. Therefore, IoT-based monitoring, digital shipment tracking, and demand forecasting are proposed to improve logistics visibility, delivery accuracy, and coordination. Market adoption has a moderate vulnerability level (RPN = 336) and is classified as a secondary risk. Slow farmer adoption is mainly related to limited technical knowledge and digital literacy. Therefore, training workshops, demonstration farms, and digital onboarding modules are proposed to improve technology understanding and adoption. Manufacturing has a lowest vulnerability level (RPN = 294) than other category. This indicates that the main supply chain risks are more strongly related to external sourcing and logistics than internal production. Therefore, annual technician certification, quality assurance standardization, and digital production monitoring are proposed to reduce operational errors and improve production consistency. Overall, procurement, warehousing, and logistics are the main vulnerabilities, while manufacturing and market adoption remain important secondary risks. These findings are consistent with previous supply chain resilience studies on supplier dependency, logistics, and operational capacity. However, this study provides a different context by showing how these vulnerabilities are connected to Political, Economic, Social, and Technological factors in a technology-based aquaculture company. In addition, each identified vulnerability is directly linked to a specific mitigation strategy, providing a practical approach for improving supply chain resilience.

The comparison between Table IV and Table V indicates that the proposed mitigation strategies are expected to reduce vulnerability across all supply chain activities. The risk reduction (RR) equation is shown in (1).

$$\text{Risk Reduction (\%)} = \left(\frac{RPN_{as\ is} - RPN_{to\ be}}{RPN_{as\ is}} \right) \times 100 \quad (1)$$

where:

RPN As Is: Risk Priority Number before mitigation implementation.

RPN To Be: Risk Priority Number after implementation of the proposed mitigation strategies.

As presented in Table VI, the comparison between the As-Is and To-Be conditions indicates that the proposed mitigation strategies can reduce supply chain vulnerability. The total RPN decreases from 2,030 to 566, representing an estimated overall risk reduction of 70.93%. Warehousing and inventory achieves the highest risk reduction (78.57%), followed by procurement, distribution and logistics, and market adoption, each with a reduction of 71.43%. Manufacturing shows a lower reduction of 57.14%. The same five experts conducted both the As-Is and To-Be assessments using the same FMEA criteria. For the To-Be assessment, the experts evaluated whether each mitigation strategy could reasonably reduce Occurrence (O) or improve Detection based on their experience and knowledge of the relevant supply chain activities. The final O and D scores were obtained by averaging the five assessments with equal weight. Severity (S)

was kept relatively stable because the impact of a disruption could not be completely eliminated. Overall, the proposed mitigation strategies are estimated to reduce supply chain vulnerability and improve supply chain resilience. Furthermore, Internet of Things (IoT)-based monitoring enhances operational visibility throughout the supply chain and supports faster decision making during operational activities. These strategies also contribute to Sustainable Development Goal (SDG) 7 by supporting the implementation of renewable energy technologies, SDG 9 through infrastructure development, digitalization, and technological innovation, and SDG 12 through more efficient inventory management, improved resource utilization, and sustainable operational practices. These findings also confirm that integrating supply chain mapping, vulnerability identification, PEST analysis, and mitigation strategy development provides a comprehensive framework for identifying critical vulnerabilities and formulating appropriate mitigation strategies to strengthen supply chain resilience in technology-enabled aquaculture companies.

IV. CONCLUSION AND FUTURE RESEARCH

This research aims to identify the main vulnerabilities affecting the supply chain of an Indonesian aquaculture technology company and formulate appropriate mitigation strategies to improve supply chain resilience under uncertain business conditions. The proposed framework integrates supply chain mapping, vulnerability analysis, Political, Economic, Social, and Technological (PEST) analysis, and mitigation strategy development to provide a comprehensive assessment of both internal operational vulnerabilities and external factors affecting supply chain performance. The study identified procurement, warehousing, and distribution and logistics as the main supply chain vulnerabilities, with delayed supply of imported components having the highest RPN (504). The proposed mitigation strategies reduced the total RPN from 2,030 to 566, representing an estimated risk reduction of 70.94%. These results indicate that the proposed mitigation strategies can reduce key supply chain risks and improve supply chain resilience. The integration of vulnerability assessment and PEST analysis also provides a practical approach for identifying risks and developing targeted mitigation strategies in technology-based aquaculture supply chains.

This research contributes to the supply chain resilience literature by integrating supply chain mapping, vulnerability identification, PEST analysis, and mitigation strategy development into a single assessment framework. Unlike previous studies that primarily focus on operational risks or macro-environmental factors separately, this research demonstrates how internal operational vulnerabilities and external business conditions can be analyzed simultaneously to support more effective mitigation planning. From a practical perspective, the proposed framework provides managers with a structured approach to identify critical vulnerabilities, prioritize mitigation strategies, and support strategic decision making under uncertain business conditions. Furthermore, the proposed mitigation strategies contribute to Sustainable Development Goal (SDG) 7 through the implementation of renewable energy technologies, SDG 9 through technological innovation, infrastructure development, and digitalization, and SDG 12 through more efficient inventory management, resource utilization, and sustainable operational practices. Despite

these contributions, this research has several limitations. First, the study was conducted in a single technology-enabled aquaculture company in Indonesia, limiting the generalizability of the findings to other industries and business environments. Second, the To-Be assessment represents a simulation based on expert judgment rather than actual post-implementation performance. Consequently, the estimated reductions in Risk Priority Number should be interpreted as projected improvements under the assumption that the proposed mitigation strategies are implemented effectively.

Future research is expected to validate the proposed framework through empirical implementation and longitudinal evaluation of mitigation performance. Further studies may involve multiple aquaculture technology companies or other technology-intensive industries to improve the generalizability of the findings and compare supply chain vulnerability characteristics across different business environments. Future research is also encouraged to integrate advanced analytical approaches, such as Bayesian Networks, System Dynamics, Monte Carlo Simulation, Digital Twin, or machine learning-based predictive analytics, to improve vulnerability prediction, scenario evaluation, and decision-support capabilities. Such developments are expected to further strengthen supply chain resilience while supporting long-term sustainability in increasingly uncertain and dynamic business environments.

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