International Journal of Sustainable Development and Planning
Vol. 21, No. 2, February, 2026, pp. 609-619
Journal homepage: http://iieta.org/journals/ijsdp

Assessing Supply Chain Management for Sustainable Ornamental Coral Trade: A Supply Chain Operations Reference-Analytic Hierarchy Process Approach in Indonesia's Bali Strait

Candra Adi Intyas[1*], Agus Tjahjono[1], Suluh Elman Swara[2], Moh Erfan Arif[3], Illisriyani Ismail[4]

[1] Department of Fisheries and Marine Socio-Economy, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang 65145, Indonesia
[2] Department of Industrial Engineering, Faculty of Engineering, Universitas Brawijaya, Malang 65145, Indonesia
[3] Department of Management, Faculty of Economics and Business, Universitas Brawijaya, Malang 65145, Indonesia
[4] Centre for Policy Research, Universiti Sains Malaysia, George Town 11800, Malaysia

Corresponding Author Email: candra.intyas@ub.ac.id

https://doi.org/10.18280/ijsdp.210213

Received: 3 December 2025
Revised: 20 January 2026
Accepted: 10 February 2026
Available online: 28 February 2026

Keywords:
supply chain management, supply chain operations reference model, coral export

ABSTRACT

The ornamental coral trade contributes to coastal livelihoods in Indonesia but operates under increasing regulatory, ecological, and operational constraints. Previous studies have largely focused on ecological conservation and trade regulation, while diagnostics of firm-level supply chain management (SCM) performance remain limited, particularly in biologically sensitive and highly regulated post-moratorium contexts. This study assesses SCM in the ornamental coral supply chain of Indonesia's Bali Strait using an integrated supply chain operations reference (SCOR) and Analytic Hierarchy Process (AHP) approach. An exploratory multi-case diagnostic design was applied, involving three supply chain actors: one exporter and two local suppliers. SCOR version 11.0 was used to evaluate performance across five attributes—reliability, responsiveness, agility, cost, and asset management efficiency—while AHP was used to derive managerial weights. The results indicate that the exporter achieved the highest overall SCM performance score (94.12), followed by the first local supplier (91.67) and the second local supplier (81.09), with an average performance score of 88.96, classified as average. Intermediate diagnostics reveal that responsiveness and asset management efficiency represent the weakest attributes among local suppliers. Although sustainability was not directly measured, the identified SCM performance patterns provide important sustainability implications for regulated and biologically sensitive marine supply chains.

1. INTRODUCTION

Indonesia is a mega-biodiverse country with significant potential in the ornamental coral trade, boasting 569 recorded coral species, around 9.6% of which are traded live [1]. Ornamental coral, such as hard and soft corals, holds high economic value due to their vibrant colours and unique shapes, which are highly sought after in the global aquarium market for hobby tourism. One of the most traded genera is *Lobophyllia*, particularly *L. corymbosa*, which is typically exported in sizes ranging from 10 to 25 cm [2, 3]. However, excessive exploitation has led to scarcity in natural habitats, prompting the implementation of an export moratorium in 2018. Additional challenges include social and institutional aspects [4]. Emphasize the importance of community empowerment and equitable distribution management to ensure long-term ecosystem sustainability and economic benefits.

The international trade in ornamental corals spans complex regulatory and ecological contexts. As a species listed under CITES Appendix II, these corals can be commercially traded but are subject to strict monitoring due to their critical ecological role as foundation species of reef ecosystems. This dual status creates a 'grey area' in which economic exploitation must be carefully balanced with conservation imperatives. From an economic perspective, the ornamental coral trade represents a high-value niche market, generating significant revenue for coastal communities and export businesses. However, its long-term viability and legitimacy are fundamentally contingent upon sustainable management practices. Effectively navigating this balance directly contributes to achieving the Sustainable Development Goals (SDGs), particularly SDG 8 (Decent Work and Economic Growth) through the development of a responsible blue economy, and SDG 14 (Life Below Water) by promoting the sustainable use of marine resources and incentivising habitat conservation through regulated trade.

In 2018, the Indonesian government, through the Ministry of Marine Affairs and Fisheries, imposed a moratorium on the trade in ornamental fish and corals in response to widespread destructive fishing and coral bleaching [2]. This policy resulted in significant losses for businesses, particularly coral farmers, who were unable to maintain their corals due to a lack of operational funding [5]. However, since the end of 2019, the ornamental coral trade has been permitted again, subject to strict regulations to ensure ecosystem sustainability. This shift has reopened economic opportunities, especially in key production areas [6].

One of the largest centres for ornamental coral production and distribution in Indonesia is the Bali Strait region, which includes the areas of Banyuwangi (East Java) and western Bali [7]. This region is known as a hub for coral farming and export activities, involving more than 38 companies, both local and large-scale exporters [8]. Ornamental coral products from the Bali Strait are exported to major markets, including the United States, Japan, China, and several European countries [7, 9]. With a steadily increasing trade value and relatively stable global demand, this region is strategically positioned in the national ornamental coral industry.

In the context of management, the ornamental coral trade involves a complex and interconnected process from upstream to downstream, known as the supply chain. A supply chain is defined as a series of entities, both individuals and organisations, that are directly involved in the flow of products, services, finances, and information from the initial supplier to the final consumer [10]. In this industry, exporters typically serve as the focal firm, collaborating with suppliers and fishermen to obtain coral in raw or semi-processed form before preparing it into export-ready products.

Every supply chain aims to maximise the value generated, the difference between the final product's value to the customer and the total cost to fulfil it. If any component within the chain operates suboptimally, the overall performance may be disrupted, thereby reducing system efficiency [11]. Especially in today's competitive global business environment, companies are expected to deliver high-quality products with fast delivery times and cost-effective pricing. Failure to meet these demands may lead customers to switch to competitors.

Therefore, effective and integrated supply chain management (SCM) from upstream to downstream is essential to support logistics efficiency, inventory control, and improved coordination among actors in the industry, including ornamental corals. An end-to-end integrated SCM enhances logistical efficiency, inventory management, actor collaboration, and fosters sustainable competitive advantage [12, 13]. Integrated SCM also enables better information exchange, transparency, and faster responsiveness to market demand changes, thereby reducing the risk of delays and inefficiencies [14]. Furthermore, adopting digital technologies and big data in SCM strengthens decision-making processes, improves supply chain visibility, and accelerates distribution flows [15, 16]. A holistic performance evaluation system is essential to ensure the effectiveness of SCM. One widely adopted approach is the supply chain operations reference (SCOR) model, a process-based framework that integrates business process reengineering, benchmarking, and performance measurement [17]. SCOR categorises supply chain activities into five primary processes: plan, source, make, deliver, and return, and evaluates performance across five key dimensions: reliability, responsiveness, agility, cost, and asset management [18]. The weighting determination in the SCOR model is conducted using the analytic hierarchy process (AHP). According to the study [19], AHP is a general theory of measurement that employs pairwise comparisons based on ratio scales, applicable to both discrete and continuous contexts.

Despite the growing body of literature on coral reef conservation, sustainable fisheries, and ornamental coral trade, most existing studies predominantly focus on ecological impacts, restoration techniques, or regulatory compliance, while firm-level supply chain performance remains underexplored. Previous research on ornamental corals in Indonesia has largely examined value chain structures, trade flows, and sustainability status using biological and multidimensional scaling approaches, such as RAPFish, without systematically diagnosing operational bottlenecks at the firm level. Meanwhile, empirical applications of the SCOR framework have been widely documented in manufacturing, agribusiness, and aquaculture commodities, but remain scarce for biologically sensitive, highly regulated export commodities such as ornamental corals. Moreover, few studies adopt a multi-case diagnostic perspective to compare the supply chain performance of different actors within a bounded supply network, particularly in post-moratorium contexts where firms must simultaneously comply with ecological regulations and market demands [6, 10, 17, 20].

Considering the significant role of the ornamental coral industry and the complexity of its SCM, a comprehensive evaluation of SCM performance in strategic areas such as the Bali Strait is essential [6]. This evaluation is expected to identify systemic weaknesses and provide improvement recommendations to enhance Indonesia's ornamental coral industry's efficiency, competitiveness, and sustainability in the global market.

Given these interconnected ecological, economic, and regulatory complexities, a systematic evaluation of the supply chain that enables this trade becomes imperative. Specifically, there is a critical need to assess whether current SCM practices among key industry actors—from local suppliers to exporters—are configured to support the sustainability goals upon which the trade's future depends. This study addresses this gap by conducting a comprehensive performance evaluation of the ornamental coral supply chain in Indonesia's Bali Strait, a major production hub. Utilising the integrated SCOR model and AHP, this research aims to: (1) measure and compare the SCM performance of different actors, (2) identify systemic weaknesses and key challenges, and (3) provide evidence-based recommendations for building a more resilient, efficient, and ecologically sustainable supply chain. The findings are expected to offer valuable insights for policymakers, industry practitioners, and conservationists in aligning economic activities with broader sustainable development objectives. This study is framed as an exploratory multi-case diagnostic assessment focusing on firm-level supply chain processes within a bounded supply network rather than industry-wide generalisation.

The SCOR framework is particularly suitable for this study because it adopts a process-based diagnostic perspective that decomposes supply chain activities into planning, sourcing, production, delivery, and returns processes, enabling the systematic identification of operational inefficiencies rather than merely ranking firm performance. Compared to efficiency frontier approaches such as data envelopment analysis (DEA), which primarily evaluate relative efficiency without revealing process-level bottlenecks, SCOR enables detailed tracing of performance weaknesses across specific supply chain functions. Furthermore, while multi-criteria decision-making techniques such as TOPSIS or ANP–ER are effective for sustainability ranking, they provide limited explanatory power regarding operational root causes. The integration of SCOR with the AHP enables managerial judgement to be incorporated through structured pairwise comparisons, allowing performance attributes and metrics to be weighted according to their contextual importance within the ornamental coral supply chain [17, 19, 21-26].

Accordingly, this study is framed as an exploratory multi-case diagnostic assessment focusing on firm-level supply chain processes within a bounded ornamental coral supply network in Indonesia's Bali Strait. Rather than aiming for industry-wide statistical generalisation, the analysis prioritises in-depth diagnosis of operational attributes across key supply chain actors, including local suppliers and exporters. This approach is consistent with process-based supply chain evaluation frameworks, where understanding context-specific bottlenecks and managerial trade-offs is more critical than estimating population-level efficiency. By adopting this perspective, the study seeks to generate actionable insights for both practitioners and policymakers operating in biologically sensitive and highly regulated marine commodity systems. While sustainability considerations provide the broader motivation for this research, the performance measurement in this study primarily captures operational SCM attributes, with sustainability implications discussed in terms of managerial practices, regulatory compliance, and long-term resource stewardship rather than direct ecological indicators.

2. METHODOLOGY

This research was conducted in the waters of the Bali Strait, covering the coastal areas of western Bali and Banyuwangi Regency, East Java. The location was selected purposively due to its strategic importance as one of Indonesia's main centres of ornamental coral production and trade. This design prioritises process-based diagnosis over statistical generalisation, enabling in-depth identification of operational bottlenecks and managerial trade-offs within a highly regulated, biologically sensitive marine commodity system.

The sample in this study was obtained using a non-probability sampling technique, namely a snowball sampling approach, starting with a key informant: an ornamental coral exporting company (focal firm). Information from this company was then used to identify the next members of the supply chain network, including two local supplier companies and coral-harvesting fishers. This technique was chosen to gradually access informants using the actual supply chain structure in the field. The resulting empirical scope comprised three companies—two local suppliers and one exporter—which together represent the core operational structure of the ornamental coral supply chain in the Bali Strait. This bounded sampling strategy ensures that all analysed actors are directly connected through transactional relationships.

Data collection was carried out using a combination of qualitative and quantitative methods. Primary data were obtained through unstructured observations, in-depth semi-structured interviews, distribution of questionnaires, and field documentation. The collected data included information on supply chain network conditions, managerial performance indicators, and challenges in the ornamental coral supply chain. Interviews were conducted with marketing and production managers from exporting and supplier companies, as well as with fishers and government officials from institutions such as the Ministry of Marine Affairs and Fisheries and the Ministry of Environment and Forestry. In addition, secondary data were obtained from government agency documents and relevant publications, covering regional profiles, regulations, and ornamental coral utilisation quota data.

To mitigate potential self-report bias inherent in interview- and questionnaire-based data collection, triangulation was applied by cross-checking managerial responses with field observations, internal operational records, and regulatory documentation. Information consistency was also verified across different supply chain actors within the same network.

Data analysis was conducted by adopting the SCOR model version 11.0, a process-based framework that divides supply chain activities into five core processes: plan, source, make, deliver, and return. Performance evaluation is carried out across five dimensions: reliability, responsiveness, agility, cost, and asset [18], as shown in Table 1. This model integrates business process reengineering, benchmarking, and performance measurement, providing a comprehensive overview of an organisation's supply chain strengths and weaknesses [27]. Study [28] across sectors has shown that implementing SCOR helps companies identify key performance indicators (KPIs) for each process, prioritise critical improvement areas, and design enhancement strategies grounded in lean supply chain principles. Additionally, SCOR can be combined with other analytical methods, such as the AHP, to determine the priority weight of each activity [29].

Table 1. Supply chain management (SCM) performance using the supply chain operations reference (SCOR) method

	Performance Attribute	Level 1 Metric
1.	Reliability	Perfect Order Fulfilment
2.	Responsiveness	Order Fulfilment Cycle
3.	Agility	Upside Supply Chain Flexibility Upside Supply Chain Adaptability Downside Supply Chain Adaptability
4.	Cost	Total Cost to Serve
5.	Asset Management Efficiency	Cash To Cash Cycle Time

Source: [18]

The AHP approach is used to determine indicator weights and measure performance hierarchically. The process involved expert and managerial interviews and preference weighting using a pairwise comparison scale. Data processing was conducted using ExpertChoice11 software. The AHP uses a hierarchical framework to synthesise multiple criteria, both qualitative and quantitative, involved in decision-making. This methodology incorporates a diverse set of alternatives and allows sensitivity analysis of the established criteria and subsequent benchmarks [18, 30].

The AHP is regarded as one of the most comprehensive systems for multi-criteria decision-making. This is attributable to its capacity to formulate problems within a hierarchical structure, integrating quantitative and qualitative criteria. The methodology is operationalised through three principal stages:

a. **Hierarchy Construction.** The initial step is to deconstruct the decision problem into a hierarchical model. At this stage, the central issue and overarching objective of the decision-making process are broken down into their constituent decision elements. These elements typically comprise decision criteria (indicators) and available alternatives (choices).
b. **Pairwise Comparison and Priority Synthesis.** The

AHP weighting process involved senior managerial respondents from each participating company who were directly responsible for procurement, production planning, and logistics decisions. All respondents had more than five years of experience in the ornamental coral industry. Pairwise comparisons were conducted separately for each company to capture firm-specific managerial priorities. Performance targets may also be established through benchmarking. Benchmarking is the process of comparing a company's current condition with that of leading competitors in the same field (*best-in-class performance*). The targets established by management are subsequently used to calculate each achievement metric value relative to its target. The weighting of performance metrics was also determined through interviews with company representatives. The weighting process adopted a subjective approach, in which metric weights were assigned based on the judgments of the respondents. Weighting was conducted by assigning relative importance to each metric, using a ranking scale. The company ranked the metrics from highest to lowest in terms of importance. Metric weights were then derived from a managerial perspective using a pairwise comparison approach, as presented in Table 2.

c. **Consistency Validation.** To ensure the reliability of the judgments, the results must be validated by calculating a Consistency Ratio (CR). The consistency of judgments was evaluated using the CR, and all pairwise comparison matrices satisfied the acceptable threshold of CR $\leqslant$ 0.10 (19, 31).

Table 2. The intensity value of importance in pairwise comparison

Intensity of Importance	Explanation
1	Both criteria contribute equally to achieving the goal.
3	Based on experience and judgment, one factor is slightly more influential.
5	Based on experience and judgment, one factor is significantly more influential.
7	The factor is strongly influential and dominates compared to the other factor.
9	The factor has an absolute and the most substantial influence among all others.
2, 4, 6, 8	Used to represent intermediate values between the priorities mentioned above.

Source: [31]

The performance calculation begins with an assessment of the selected matrix based on interviews with company representatives. The resulting matrix score reflects the actual matrix score currently in place at the company. The actual score is compared with the target achievement to obtain the current achievement metric score. The measurement of supply chain performance begins by assigning weights to each metric and attribute based on their level of importance. Next, the actual value of each metric is compared to the target set by management to calculate the achievement score. This score is then multiplied by each [18, 31]. Based on the normalisation procedure described above, the current achievement metric performance metrics were classified based on their directionality into:

- Benefit-type metrics, where higher values indicate better performance (e.g., perfect order fulfilment, supply chain adaptability).
- Cost-type metrics, where lower values indicate better performance (e.g., cash-to-cash cycle time).

Benefit-type metrics were normalised using the ratio of actual to target values, whereas cost-type metrics were normalised using the inverse ratio of target to actual values. To ensure comparability and avoid score inflation, all normalised metric values were capped at 100. This capping applies only to metric normalisation at the lowest measurement level; aggregated metric- and attribute-level scores are treated as intermediate diagnostic indicators and may exceed 100 prior to final performance aggregation. Metrics for which both actual and target values were zero were treated as non-applicable and excluded from aggregation. The current achievement metric score is expressed as a normalised score S_{ijk} which serves as the input for subsequent attribute-level aggregation.

$$S_{ijk} = \frac{\text{Actual}_{ijk}}{\text{Target}_{jk}} \times 100\% \text{ (Benefit – type metrics)}$$

$$S_{ijk} = \frac{\text{Actual}_{ijk}}{\text{Target}_{jk}} \times 100\% \text{ (Cost – type metrics)}$$

where, S_{ijk} denotes the normalised score of the metric k under attribute j for company i. Metric-level scores are then aggregated into attribute-level performance scores using weights derived from the AHP:

$$A_{ij} = \sum_{k} w_{jk}\ S_{ijk}, \sum_{k} w_{jk} = 1$$

where, A_{ij} represents the performance score of the attribute j for company i, and w_{jk} denotes the AHP-derived weight of metric k.

The overall SCM performance score for each company is calculated by aggregating attribute-level scores using attribute weights obtained from AHP:

$$P_i = \sum_{j} W_j\ A_{ij}, \sum_{j} W_j = 1$$

where, P_i denotes the final SCM performance score for the company i, and W_j represents the weight of the attribute j.

The current achievement metric performance -and attribute-level scores (S_{ijk} and A_{ij}) are treated as intermediate diagnostic indicators and may exceed 100, reflecting performance surpassing predefined targets. Only the final aggregated SCM performance score (P_i) is interpreted and classified on a bounded 0–100 scale for comparative evaluation across supply chain actors. The identification of improvement solutions was conducted by evaluating the performance assessment results. SCM performance aspects that did not meet the company's target levels were further examined through their underlying metrics. Derived metrics with low achievement values were identified to diagnose the specific issues associated with each metric. These identified issues served as the basis for formulating appropriate improvement solutions to enhance future supply chain performance. The proposed improvement solutions were determined through discussions with company representatives and a review of relevant literature, enabling a comprehensive understanding of the identified problems and the selection of appropriate corrective actions. This methodological design emphasises diagnostic depth over statistical generalisation.

3. RESULTS AND DISCUSSION

3.1 Performance of the ornamental coral supply chain

The assessment of supply chain performance in this study uses the SCOR 11.0 model as a diagnostic framework to interpret both external and internal performance outcomes. Within this framework, performance metrics are grouped into customer-oriented (external) and company-oriented (internal) dimensions. The external dimension reflects performance in terms of reliability, responsiveness, and agility, which are directly associated with the firm's ability to meet customer requirements. In contrast, the internal dimension captures cost performance and asset management efficiency, indicating how effectively the company manages its internal resources to support supply chain operations [18].

Table 3. Classification of standard values for the total supply chain performance score

	Performance Score	Category
1	< 60	Unacceptable
2	60 – 69	Poor
3	70 – 79	Below Average
4	80 – 89	Average
5	90 – 94	Above Average
6	95 – 100	Excellent

Source: [32]

The results suggest that an effective supply chain performance measurement system must align closely with the firm's strategic objectives. Emphasising performance outcomes rather than isolated operational activities enables management to more effectively assess whether supply chain practices contribute to overall organisational goals. This shift from efficiency-focused measures toward effectiveness-oriented evaluation highlights the importance of managerial judgment in distinguishing between practices that merely improve short-term efficiency and those that generate sustainable performance improvements. Accordingly, the observed performance scores are interpreted not only as numerical indicators but also as managerial signals that support decision-making aimed at improving supply chain performance [32]. Standard reference values for supply chain performance are presented in Table 3 to facilitate contextual interpretation of the results.

The formulation of improvement actions began with an analysis of the derived metrics associated with the performance attributes identified through the performance assessment results. Derived metrics with low target achievement values for each attribute were subsequently discussed with company representatives to identify the underlying operational issues associated with these metrics. These discussions aimed to clarify the factors contributing to performance gaps. The identified issues then served as the basis for determining appropriate improvement actions. Improvement efforts were prioritised for performance attributes whose scores had not yet met management-defined targets, thereby providing a focused, management-oriented approach to enhancing future SCM performance. The SCM performance scores are presented in Table 4.

Table 4. Supply chain operations reference (SCOR) scores in the coral supply chain companies

	Performance Attribute	AHP Weight	Performance Score	SCM Performance Score
Local Supplier (PT. LSA)				
1	Reliability	0.232	96.65	22.42
2	Responsiveness	0.451	90.07	40.62
3	Agility	0.137	168.44	23.08
4	Cost	0.115	29.33	3.37
5	Asset Management Efficiency	0.064	34.08	2.18
Total Supply Chain Management (SCM) Performance Score				**91.67**
Local Supplier (PT. DAM)				
1	Reliability	0.576	92.45	53.25
2	Responsiveness	0.095	54.71	5.20
3	Agility	0.131	66.03	8.65
4	Cost	0.123	83.73	10.30
5	Asset Management Efficiency	0.075	49.25	3.69
Total Supply Chain Management (SCM) Performance Score				**81.09**
Exporter				
1	Reliability	0.332	98.32	32.97
2	Responsiveness	0.317	87.59	27.77
3	Agility	0.172	100.00	17.20
4	Cost	0.092	82.37	7.58
5	Asset Management Efficiency	0.087	96.74	8.61
Total Supply Chain Management (SCM) Performance Score				**94.12**
Average SCM Performance Score				**88.96**

Source: Own elaboration based on the experiment's results

The attribute-level scores reported in Table 4 represent intermediate diagnostic results derived from the SCOR–AHP aggregation process. Attribute values exceeding 100 indicate achievement beyond predefined managerial targets at the aggregation stage and are intended to highlight specific operational strengths and constraints prior to final performance consolidation. Three companies were evaluated for their performance in the ornamental coral supply chain in the Bali Strait region. Based on the calculations, the SCOR-based performance assessment indicates variation in SCM performance across the three analysed companies. The exporter recorded the highest overall SCM performance score, 94.12, followed by the first local supplier (PT. LSA) with a score of 91.67 and the second local supplier (PT. DAM) with a score of 81.09. These results highlight differences in operational capability and resource management across supply chain actors.

The average performance score across the three companies was 88.96, placing them in the "average" category. According to the classification by Monczka et al. [31], this indicates that the SCM performance has not yet reached best-practice benchmarks and requires improvements in several key performance attributes. Improvements are recommended for those attributes whose performance scores have not yet met management targets.

Although the overall SCM performance falls within the average category, the results suggest that several attributes have not yet reached best-practice benchmarks. In particular, responsiveness and asset management efficiency consistently recorded lower scores across local suppliers, indicating structural constraints rather than isolated operational issues.

This performance pattern is consistent with previous studies on SCM in aquaculture and biologically sensitive commodities, which report that responsiveness and asset management efficiency tend to be weaker than reliability due to long production cycles, environmental uncertainty, and regulatory constraints [17, 31, 32]. Similar findings have been observed in marine-based value chains, where biological growth processes limit flexibility and increase actors' dependence on coordination.

While sustainability is not directly quantified through ecological indicators in this study, the identified SCM performance patterns have important sustainability implications. Improvements in responsiveness, planning accuracy, and asset management efficiency can reduce reliance on wild-coral sourcing, support compliance with regulatory frameworks, and enhance the long-term economic viability of ornamental coral enterprises.

The performance measurement system for procurement and supply chains must align with the company's objectives, as inappropriate indicators can be detrimental. Today's performance measurement focuses more on outcomes than activities, emphasising effectiveness over efficiency. Management must also be able to distinguish between good and poor procurement practices to improve supply chain performance [31]. The classification serves as a managerial benchmark rather than an absolute efficiency threshold.

3.2 Evaluation of supply chain performance based on the Supply Chain Operations Reference Model

The first local supplier's SCM performance is PT. LSA's supply chain performance, which scored 91.67, placing it in the above-average category. Continuous improvement in supply chain operations is necessary to maintain or improve this level of performance, with a focus on achieving metrics that have not yet reached the target value (100%), as shown in Table 5.

Attribute scores represent intermediate performance indicators and may exceed 100 prior to final score aggregation. PT. LSA performed well in reliability, with an average achievement score of 96.25%, reflecting a strong reliance on suboptimal stock due to limited supply and varying coral quality, particularly when sourced from the wild. Although extended delivery deadlines have been agreed upon, around 1–5% of corals still arrive damaged and go unpaid. Costa et al. [33] and Todinanahary et al. [34] recommended solutions include improved packaging technologies, such as LED-lit boxes and oxygenation systems, to maintain water quality during shipment and species-specific handling protocols to reduce shipping stress.

The responsiveness attribute of PT. LSA is in the moderate category with an average score of 81.67%. However, two key metrics remain suboptimal: source cycle time (70%) and make cycle time (75%). A strong dependence on weather conditions leads to a low source cycle time, as coral supplies originate from the wild or in-situ nurseries that become inaccessible during adverse weather. Meanwhile, the cycle time is not yet optimal due to the long growth period required for coral transplantation, which is influenced by environmental factors. A proposed solution is to develop ex-situ cultivation areas to reduce dependence on natural sources. Technologies such as the modular Maritechture™ system [32], the introduction of companion fish to enhance coral health [35], and the use of selective breeding to develop environmentally resilient species [29] have the potential to accelerate production cycles and significantly improve coral farming efficiency.

Table 5. Achievement metric in PT. LSA's supply chain management (SCM) performance

No	Metric	Actual Value	Target / Ideal	Achievement Metric (%)
Reliability				
1	% of orders delivered in full	100%	100%	100.00
2	Delivery performance to customer commit date	90%	100%	90.00
3	Documentation accuracy	100%	100%	100.00
4	Perfect condition	95%	100%	95.00
Average				**96.25**
Responsiveness				
1	Source cycle time	20 days	14 days	70.00
2	Make cycle time	8 months	6 months	75.00
3	Deliver cycle time	24 hours	24 hours	100.00
Average				**81.67**
Agility				
1	Upside Supply Chain Flexibility	14 days	14 days	50.00
2	Upside Supply Chain adaptability	75%	40%	187.50
3	Downside of Supply Chain adaptability	80%	40%	200.00
Average				**163.00**
Cost				
1	Planning Cost	10%	20%	200.00
2	Source Cost	40%	40%	100.00
3	Make Cost	10%	10%	100.00
4	Deliver Cost	0%	0%	100.00
Average				**125.00**
Efficiency Management Asset				
1	Cash-to-cash cycle time	28 days	7 days	25.67
2	Return to the on-supply chain fixed asset	40%	40%	100.00
3	Return on working capital	10%	30%	33.00
Average				**52.78**

Source: Own elaboration based on the experiment's results

PT. LSA has an excess in terms of agility (163%) and cost (125%), but shows significant weakness in asset management efficiency, with a score of only 52.78%. Low cash-to-cash cycle time (25%) and return on working capital (33%) are due to delayed payments from exporters, as agreed at the outset, which slows cash flow and delays payments to fishermen. Solutions include renegotiating payment terms to introduce a down payment system and setting a tolerance for coral damage of less than 5% that does not affect the total payment. Similar strategies [36]. Structured decision-making and flexible contracts have proven effective in improving asset efficiency and financial cycles in asset-heavy industries. Enhancing these aspects can support financial sustainability and global competitiveness.

Subsequently, the second local supplier, PT. DAM demonstrated an SCM performance score of 81.09. This score indicates that the supply chain performance falls within the average category. It suggests that improvement strategies are needed to enhance supply chain performance. Improvements are recommended, particularly for performance attributes that have not yet met the company's target benchmarks, and for achieving each metric related to PT. DAM's SCM performance is presented in Table 6.

Table 6. Achievement metric in PT. DAM's supply chain management (SCM) performance

No	Metric	Actual Value	Target / Ideal	Achievement Metric (%)
Reliability				
1	% of Orders Delivered in Full	85%	100%	85.00
2	Delivery performance to customer commit date	80%	100%	80.00
3	Documentation Accuracy	100%	100%	100.00
4	Perfect Condition	90%	100%	90.00
Average				88.75
Responsiveness				
1	Source cycle time	45 days	14 days	50.00
2	Make cycle time	8 months	6 months	75.00
3	Deliver cycle time	10 hours	10 hours	100.00
Average				68.70
Agility				
1	Upside Supply Chain Flexibility	28 days	14 days	50.00
2	Upside Supply Chain adaptability	30%	40%	50.00
3	Downside of Supply Chain adaptability	40%	40%	100.00
Average				75.00
Cost				
1	Planning Cost	30%	20%	66.67
2	Source Cost	60%	40%	66.67
3	Make Cost	10%	10%	100.00
4	Deliver Cost	20%	0%	80.00
Average				78.33
Asset Management Efficiency				
1	Cash-to-cash cycle time	7 days	7 days	100.00
2	Return to the on-supply chain fixed asset	35%	40%	87.50
3	Return on working capital	30%	30%	100.00
Average				95.83

Source: Own elaboration based on the experiment's results

The reliability attribute of PT. DAM scores 88.75%, indicating moderate performance due to low fulfilment (% of delivered in full), on-time delivery, and product condition. These issues are mainly caused by third parties' reliance on wild coral, while inconsistent inspection by buyers also results in payment deductions. According to Banaszak et al. [37], improving operational coordination and management practices can help address these issues, including enhancing communication, clarifying delivery arrangements, and aligning quality standards to reduce disputes. Improving operational coordination and management practices can help address these issues, including enhancing communication, clarifying delivery arrangements, and aligning quality standards to reduce disputes. Furthermore, flexibility in delivery deadlines helps manage volatile stock conditions. Previous studies [32, 38] suggest that diversifying raw material sources and developing ex-situ infrastructure can reduce third-party dependency and improve stock control.

The responsiveness attribute of PT. DAM scored 68.70% and was categorized as poor. The low source cycle time (31.11%) is due to the lack of permits to use wild coral, which forces reliance on external suppliers and results in uncertain availability. The cycle time (75%) remains lengthy due to the 6 to 14-month coral transplantation process. Enhancing market forecasting and coordination between production and marketing is essential for responsive inventory management. Schmidt-Roach et al. [39] suggested improvements include better production capacity planning, advanced coral maintenance technology, and establishing safety stocks to reduce supply risks. Neil et al. [40] integrated aquaculture systems with companion fish to boost coral growth and health, while Van Oppen et al. [41] assisted evolution and selective breeding to improve production efficiency.

The agility attribute of PT. DAM averages 75%, categorized as below average. This is due to low performance in upside supply chain flexibility (50%) and adaptability (75%), stemming from the company's reliance on in situ coral transplantation, which lacks flexibility. Ex-situ transplantation, which could build safety stock, remains underutilized due to technical and skill limitations. Previous studies [3, 42, 43] suggest that improvements should focus on enhancing ex-situ capacity through technical training and HR development. Furthermore, studies [7, 37, 39] indicate that modular nursery infrastructure can streamline operations and increase flexibility, while data-driven stock monitoring enhances responsiveness to market shifts. These improvements are expected to enhance operational flexibility, reduce supply uncertainty, and strengthen the adaptive capacity of the supply chain, thereby supporting both economic performance and long-term sustainability of ornamental coral enterprises.

PT. DAM's cost attribute was scored 78.33%, categorized as below average. Planning cost (66.67%) is high due to licensing and asset investments for ex-situ development, while source cost (66.67%) is burdened by dependence on broodstock purchases from Makassar due to permit restrictions. The cost of delivery (80%) suffers from inefficient shipment planning. A combination of efforts is expected to improve PT. DAM's overall supply chain cost management. To address these issues [9, 32, 44, 45], the company should build broodstock inventory through partnerships in Sulawesi and place bulk orders to reduce source costs. Logistics efficiency can be improved through regular scheduling, optimal routing, and vehicle use. Eliminating low-impact activities, such as excessive nursery cleaning, can enhance cost efficiency.

PT. DAM's asset management efficiency scored 95.83%, which is categorized as excellent. However, the return to supply chain fixed assets remains suboptimal at 87.5% due to high investment in fixed capital for ex-situ cultivation. To improve this, the company should expand partnerships with exporters to include investment or capital support to enhance asset efficiency. The approach [3, 39, 46] aligns with coral restoration strategies that promote modular, collaborative infrastructure for cost-effective asset management. Like reef restoration, ex-situ operations can benefit from efficient technologies to achieve financial and ecological sustainability.

Afterwards, the exporter's total supply chain performance score was 94.12. This value indicates that the company's supply chain performance falls into the above-average category. Further improvements are encouraged to help the company maintain or enhance its performance. The achievement of each metric contributing to the Exporter's SCM performance can be seen in Table 7.

Table 7. Achievement metric in exporters' supply chain management (SCM) performance

No	Metric	Actual Value	Target / Ideal	Achievement Metric (%)
Reliability				
1	% of Orders Delivered in Full	100%	100%	100.00
2	Delivery performance to customer commit date	90%	100%	90.00
3	Documentation Accuracy	100%	100%	100.00
4	Perfect Condition	100%	100%	100.00
Average				97.50
Responsiveness				
1	Source cycle time	14 days	14 days	100.00
2	Make cycle time	21 days	14 days	66.67
3	Deliver cycle time	38 hours	32 hours	84.21
Average				83.63
Agility				
1	Upside Supply Chain Flexibility	14 days	14 days	100.00
2	Upside Supply Chain adaptability	20%	20%	100.00
3	Downside Supply Chain adaptability	40%	40%	100.00
Average				100.00
Cost				
1	Planning Cost	25%	20%	80.00
2	Source Cost	70%	40%	57.00
3	Make Cost	10%	10%	100.00
4	Deliver Cost	0%	0%	100.00
Average				84.29
Asset Management Efficiency				
1	Cash-to-cash cycle time	7 days	7 days	100.00
2	Return to on-supply chain fixed asset	60%	70%	85.71
3	Return on working capital	30%	30%	100.00
Average				95.24

Source: Own elaboration based on the experiment's results

Exporter shows excellent reliability, with an average score of 97.50%, supported by strategic partnerships with French and Belgian importers that also provide capital assistance. However, delivery performance to the customer commitment date remains at 90% due to mismatches between stock and consumer demand. The company mitigates this by requesting extended shipment deadlines under a free on board (FOB) arrangement, in which importers bear the delivery costs. To maintain high reliability, exporters should adopt demand-based stock management and adjust shipment schedules accordingly [47, 48]. Long-term collaboration and capital support from partners also enhance supply chain reliability and operational efficiency.

The responsiveness attributes of exporters score an average of 83.63%, placing them in the average category. The cycle time of make is suboptimal at 66.67% due to the lengthy coral treatment and recovery process, which includes sorting, healing physical damage, and obtaining required export documents such as quarantine certificates and foreign transport permits. These procedures typically take 1 to 2 weeks. Coral recovery itself takes 7 to 21 days, depending on the species. The exporter should enhance coordination with importers to optimise stock scheduling and improve responsiveness. The company has also partnered with local firms to build safety stock and actively forecast global market trends, reflected in its strong agility performance (100%). These efforts align with McLeod et al. [38], who emphasized integrating biological recovery timelines into the coral supply chain planning to avoid product degradation and financial losses.

Exporter achieved a delivery cycle time score of 84.21%, highlighting the need for improvement due to licensing issues, weather disruptions, and poor shipment planning. To address this, according to Li et al. [22], the company should adopt a systematic transportation management system that optimises costs, time, routes, and schedules, including regular and backup plans, and ensure vehicle availability for airport transport. This aligns with Guo et al. [49], who found that integrating production and transport planning with eco-friendly modes and accurate scheduling can boost supply chain efficiency and cut logistics costs by up to 21.9%.

Exporter's cost attribute scored 84.29%, categorised as average, with planning cost (80%) and source cost (57.14%) needing improvement. Planning costs rise due to unpredictable natural factors such as extreme weather, while high sourcing costs stem from reliance on local suppliers, leading to delays and limited availability. Solutions suggested by Guritno and Tanuputri [50] include forming strategic partnerships for ex-situ cultivation to maintain safety stock and establishing long-term agreements with alternative suppliers to secure a sustainable coral supply.

Exporter scored 95.24% in asset management efficiency, categorised as excellent, but needs improvement in the return-to-supply-chain-fixed-assets metric (85.71%) due to high capital investment in coral care technologies. To optimise returns, the company should enhance production fulfilment by integrating scheduling and partnering with local firms to increase production capacity [51]. Furthermore, strengthening coral care skills is essential for reducing operational costs and improving efficiency [52].

4. CONCLUSIONS

This study employed an exploratory multi-case diagnostic approach to assess SCM performance in the ornamental coral trade of Indonesia's Bali Strait using an integrated SCOR–AHP framework. The results demonstrate heterogeneous performance patterns across supply chain actors, with the exporter achieving the highest overall SCM performance score, followed by local suppliers. Although the final SCM performance score indicates an average level of performance, the intermediate attribute-level results reveal persistent constraints in responsiveness and asset management efficiency, particularly among upstream suppliers.

The SCOR–AHP framework enabled systematic identification of operational strengths and bottlenecks through a hierarchical aggregation process, in which metric- and attribute-level scores function as intermediate diagnostic indicators and the final aggregated score provides a comparable performance benchmark. This diagnostic capability is especially relevant for biologically sensitive and highly regulated supply chains, where operational trade-offs are shaped by ecological, regulatory, and market constraints.

While sustainability was not directly measured through ecological indicators, the observed SCM performance patterns carry important sustainability implications. Improvements in planning accuracy, responsiveness, and asset management efficiency can reduce reliance on wild coral extraction, enhance regulatory compliance, and support the long-term economic viability of ornamental coral enterprises.

Given its exploratory multi-case design and bounded supply chain scope, the findings of this study should be interpreted as context-specific insights rather than industry-wide generalisations. Nevertheless, the analytical framework and performance patterns presented may inform future SCM assessments and policy-oriented interventions in other regulated and biologically sensitive marine commodity supply chains.

A significant limitation in this study of the ornamental coral supply chain was limited access to secondary trade data, particularly public data. This challenge arose from an ongoing jurisdictional dispute between two ministries, which consequently extended the research period.

ACKNOWLEDGMENT

We would like to express our sincere gratitude to the Universitas Brawijaya Visiting Lecturer Program 2025.

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