

Enhancing Economic Performance in Maritime Transportation via Strategic Partnerships: Empirical Insights from SEM-DEA Hybrid Modelling in an Emerging Market



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Abstract: This study investigates the determinants of supply chain efficiency in maritime transportation enterprises confronting persistent volatility in marine fuel prices and identifies optimal strategic alliance partners. Drawing on strategic alliance theory and supply chain management principles, it develops a relational network model that positions strategic alliance intensity as the central moderator among digital transformation capability, supply chain integration, supply chain resilience and risk management capability, green logistics and environmental compliance, and operational and asset management capability, all converging on supply chain efficiency. Structural equation modelling of survey data reveals that operational and asset management capability exerts the sole substantive direct positive effect on supply chain efficiency ($\beta = 0.47$), with the remaining antecedents influencing the outcome primarily through mediated pathways. Input-oriented super slack-based measure data envelopment analysis under variable returns to scale, applied to 2025 audited financial statements, constructs virtual composite decision-making units and identifies the alliance between the Hanoi-based container specialist (DMU10) and the Da Nang-based bulk operator (DMU8) configuration yielding maximal efficiency gains. Theoretically, the research clarifies mediated relational pathways in capital-intensive logistics. Practically, it provides executives and policymakers with a replicable toolkit for partner selection that may help mitigate fuel-price exposure, support decarbonization, and strengthen resilience.

Keywords: digital transformation; strategic alliance; green logistics; maritime transportation; maritime logistics.

JEL Classification: L91; L25; L14; C61; Q56.

Introduction

The maritime transportation industry, which underpins more than 80 percent of global merchandise trade by volume and facilitates the seamless movement of approximately 12.7 billion tons of cargo annually, faces an existential operational crisis driven by persistent volatility in marine bunker fuel prices. This study advances urgent, evidence-based strategic solutions for maritime shipping enterprises confronting escalating fuel costs, with a particular focus on container and bulk carriers operating under conditions of geopolitical instability and regulatory stringency. By integrating strategic alliance theory with advanced supply chain management principles, the research delineates a rigorous framework for alliance selection that enhances supply chain efficiency while delivering measurable resilience against energy-price shocks. The investigation is organized around three interconnected pillars: the

contemporary dynamics of marine fuel price escalation, the profound macroeconomic repercussions of diminished shipping efficiency, and the imperative for systematic computation of optimal strategic alliances to safeguard corporate viability and broader societal welfare.

First, marine fuel prices have exhibited extreme volatility and recurrent upward spikes throughout the mid-2020s, transforming bunker procurement from a manageable operating expense into a dominant determinant of voyage economics. Bunker fuel, primarily very low sulfur fuel oil (VLSFO), high sulfur fuel oil (HSFO) for scrubber-equipped vessels, and marine gas oil (MGO), typically constitutes 40 to 60% of total voyage costs for conventional vessels, a proportion that surges to over 85% during acute price spikes in dry-bulk trades. As of March 2026, geopolitical tensions in the Middle East, particularly disruptions in the Strait of Hormuz (a conduit for nearly 20% of global oil flows), have triggered sharp escalations: the 380 HSFO index rose by USD 9.55 to USD 790.51 per metric ton, VLSFO advanced by USD 15.64 to USD 949.88 per metric ton, and MGO LS recorded a USD 28.21 increase to an all-time high of USD 1,609.79 per metric ton, surpassing previous records in the MABUX series dating to 2001. These movements represent cumulative weekly gains of 30–35% in key bunkering hubs such as Singapore and Rotterdam, compounding earlier rerouting-induced fuel burn from Red Sea disruptions in 2023–2024 that already elevated global ton-miles by an estimated 17% in 2024. Although average VLSFO prices moderated to USD 535 per metric ton across 2025 (a 14.4 % decline from 2024 levels), the resurgence in 2026 underscores the structural fragility of supply chains dependent on Middle Eastern crude derivatives, exacerbated by International Maritime Organization (IMO) 2020 sulfur cap regulations and the impending Net-Zero Framework deliberations. For the container shipping segment alone, sustained price elevation at current levels could impose an additional industry-wide bunker bill of USD 29.5–34.5 billion annually, according to Sea-Intelligence modelling calibrated against Maersk's 2025 expenditure of USD 6.3 billion. Such cost inflation directly inflates the cost of goods sold, compresses earnings before interest and taxes, and compels emergency fuel surcharges that propagate inflationary pressures downstream. Traditional cost-mitigation tactics (slow steaming, route optimization, or scrubber retrofits) have proven insufficient amid multidirectional price swings and supply shortages, necessitating collaborative mechanisms that transcend firm-level interventions.

Second, the operational and financial efficiency of maritime transportation enterprises exerts outsized leverage on national economies and the architecture of global commerce. Seaborne trade not only accounts for over 80 percent of international merchandise volume but also generates multiplier effects that permeate manufacturing, retail, energy security, and food supply chains across continents. In 2024, maritime volumes expanded by 2.2% to 12.72 billion tons, yet growth decelerated sharply to a projected 0.5% in 2025 amid rerouting penalties and capacity constraints, while global trade value approached a record USD 35 trillion. For export-dependent economies (particularly in Asia-Pacific and emerging markets) elevated freight rates stemming from fuel volatility erode trade competitiveness, inflate consumer prices, and constrain gross domestic product growth. A 1% increase in shipping costs can translate into measurable reductions in export volumes and household purchasing power, disproportionately affecting least-developed countries and small-island developing states already burdened by higher insurance premiums and longer transit times. At the firm level, pre-alliance benchmarking reveals that fuel-driven inflation in administrative and voyage expenses erodes profit-after-tax margins, with major liner operators reporting compressed returns on assets despite record container throughput in 2025. This inefficiency cascades systemically: higher freight rates feed into global value chains, amplifying production costs in downstream industries and contributing to broader macroeconomic instability. Empirical studies on container alliances (such as the 2M, Ocean Alliance, and THE Alliance configurations operational since 2017) demonstrate that uncoordinated responses exacerbate volatility in freight rates when demand shocks predominate, whereas coordinated capacity deployment can stabilize supply-side fluctuations. The present research extends this literature by quantifying how isolated operational inefficiencies (manifest in suboptimal asset utilization, fragmented digital integration, and inadequate risk management) amplify exogenous fuel shocks, thereby threatening the resilience of the very logistics backbone that sustains 90 percent of global trade by volume in certain estimates.

Third, the convergence of these pressures underscores the urgent necessity to identify, evaluate, and implement the most efficacious strategic alliances through systematic, quantitative analysis. Conventional independent strategies have reached diminishing returns against persistent energy-cost volatility, regulatory mandates for decarbonization, and the competitive imperatives of mega-vessel deployment. This study therefore advances a comprehensive relational network model that positions strategic alliance intensity as the central moderator among five complementary capabilities (digital transformation capability, supply chain integration, supply chain resilience and risk management capability, green logistics and environmental compliance, and operational and asset management capability) all converging upon supply chain efficiency as the pivotal performance outcome. These constructs are conceptualized as interdependent nodes within a directed graph, wherein bidirectional

linkages capture synergistic amplification: for example, elevated alliance intensity facilitates shared digital platforms for real-time fuel optimization and joint green logistics initiatives that simultaneously reduce emissions compliance costs and enhance resilience to price shocks. The analytical procedure employs a three-stage protocol. Initially, antecedent factors are delineated and validated against domain-specific maritime literature. Subsequently, pre-alliance business efficiency is benchmarked via input-output analysis of decision-making units derived from corporate financial statements, utilizing total assets, cost of goods sold, and administrative expenses as inputs, sales revenue as throughput, and profit after tax as the terminal output metric. Finally, post-alliance scenarios are simulated through composite decision-making units (focal firm plus prospective partners) to isolate the configuration yielding maximal efficiency gains, followed by interpretive discussion of underlying mechanisms such as economies of scale in bunker procurement, coordinated asset redeployment, and risk-pooling protocols.

This methodological architecture not only addresses immediate fuel-price imperatives but also generates scalable societal dividends: stabilized freight rates that dampen inflationary transmission, accelerated adoption of low-carbon technologies via shared compliance investments, and fortified global supply chain resilience against future exogenous shocks. Theoretically, the work enriches strategic management and logistics scholarship by embedding alliance intensity within a maritime-specific nomological network, thereby bridging gaps in prior research that has largely examined container alliances through qualitative or aggregate lenses without granular pre-post efficiency decomposition. Practically, it furnishes shipping executives and policymakers with a replicable diagnostic and prescriptive toolkit (grounded in data envelopment principles) for alliance selection that prioritizes measurable improvements in supply chain efficiency while aligning with IMO decarbonization trajectories and geopolitical realities. In an era when maritime logistics constitutes the circulatory system of the world economy, the timely deployment of optimally calibrated strategic alliances emerges not as a competitive luxury but as an existential imperative for corporate survival, national competitiveness, and sustainable global prosperity.

1. Literature Review

The maritime transportation sector, responsible for over 80 % of global merchandise trade by volume and approximately 12.7 billion tons of cargo annually, continues to confront acute operational challenges stemming from sustained volatility in marine bunker fuel prices. Geopolitical disruptions, regulatory mandates under the International Maritime Organization, and supply-chain rerouting have transformed fuel procurement into the dominant driver of voyage economics. In response, a growing body of research published between 2021 and 2026 has examined the determinants of supply chain efficiency in sea freight operations, with particular attention to operational and asset management capability, digital transformation capability, supply chain integration, supply chain resilience and risk management capability, green logistics and environmental compliance, and strategic alliance intensity.

Recent empirical work underscores the primacy of operational and asset management capability. Studies employing data envelopment analysis frameworks have consistently demonstrated that fleet modernization, real-time scheduling, container repositioning, and elevated asset utilization rates remain the strongest predictors of cost minimization and service reliability in capital-intensive networks (Fan *et al.* 2022; Rafal Haffer, 2018). Complementary investigations have highlighted the enabling roles of digital transformation capability, showing how Industry 4.0 technologies improve visibility and decision speed (Raza *et al.* 2023; Mollaoglu *et al.* 2026; Bóna *et al.* 2026). Parallel streams document the contributions of supply chain integration in reducing coordination frictions, supply chain resilience and risk management capability in buffering exogenous shocks, and green logistics and environmental compliance in aligning regulatory demands with long-term competitiveness (Xu *et al.* 2026; Engelaitis *et al.* 2026; Šateikiene *et al.* 2026).

Strategic alliance research has gained momentum as a unifying lens. Ghorbani *et al.* (2022) provided a comprehensive review of container shipping alliances, emphasizing economies of scale in vessel deployment and risk pooling, yet noted persistent instability in partnership outcomes. Loon *et al.* (2023) applied partial least squares structural equation modelling to Malaysian ocean carriers and found that governance trust partially mediates the relationship between alliance antecedents and supply chain performance. Akam *et al.* (2024) similarly confirmed positive correlations between collaborative partnerships and logistics efficiency in container operations. More recent analyses of the 2025 alliance reshuffling (Ocean Alliance extension, Gemini Cooperation formation) further illustrate how vessel-sharing arrangements influence freight rates and service coverage (Zi *et al.* 2026; Chen *et al.* 2025; Lin Li, 2026).

Despite these advances, important gaps persist. Most studies remain either qualitative, aggregate in scope, or focused on single constructs, offering limited insight into firm-level efficiency dynamics under variable returns to scale. Few investigations embed strategic alliance intensity as a central moderator within a relational network model

that simultaneously links the five complementary capabilities to supply chain efficiency. Moreover, quantitative assessments capable of benchmarking pre-alliance performance against simulated post-alliance composite decision-making units (particularly through advanced super slack-based measure data envelopment analysis grounded in audited financial statements) are scarce, especially within emerging-market contexts such as Vietnam's north–central coastal corridor.

This study addresses these voids by integrating strategic alliance theory with supply chain management principles in a maritime-specific nomological network. Theoretically, it clarifies potential mediated pathways in energy-intensive logistics. Practically, it equips shipping executives and policymakers with a replicable diagnostic toolkit for partner selection that mitigates fuel-price shocks, accelerates decarbonization, and fortifies the resilience of global trade arteries. In an era of structural supply-chain fragility, such an integrated, evidence-based framework constitutes both a scholarly contribution and an operational imperative.

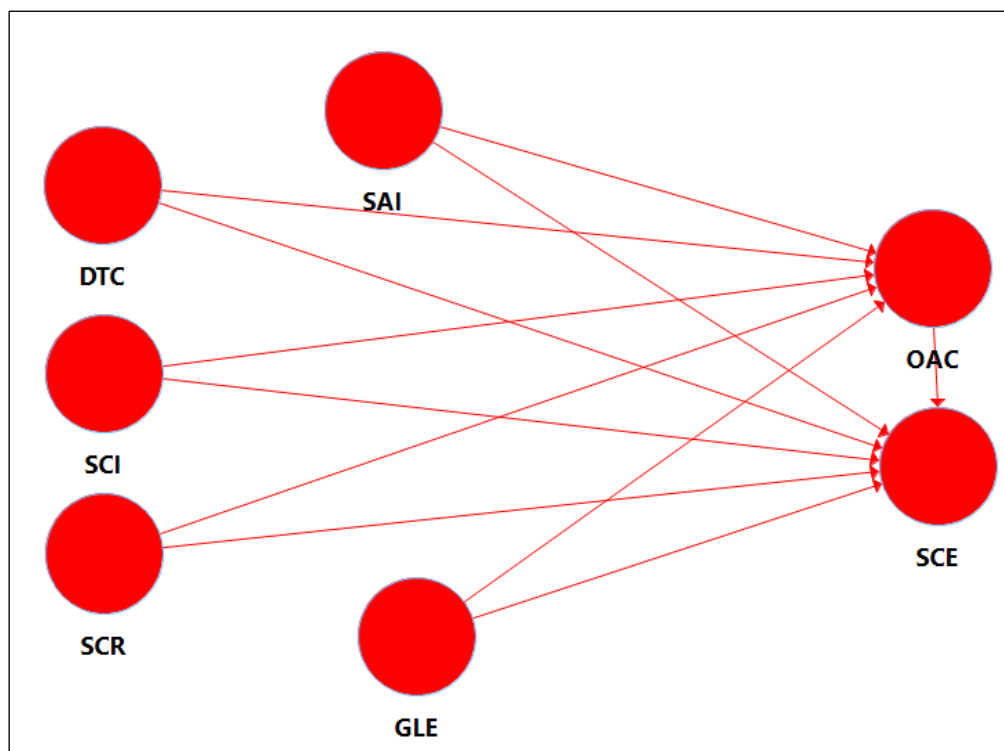
2. Materials and Methods

The research process in this study is structured into three sequential steps, grounded in an integrated conceptual framework that links strategic alliance intensity, digital transformation capability, supply chain integration, supply chain resilience and risk management capability, green logistics and environmental compliance, and operational and asset management capability to supply chain efficiency. This approach addresses the urgent need for maritime transportation companies to counter rising fuel prices through evidence-based alliance strategies, offering both theoretical advancement in logistics and practical solutions for cost containment and resilience.

Step 1: Identification of Factors Influencing Supply Chain Efficiency

This phase systematically identifies and models the six antecedent constructs as interconnected determinants of supply chain efficiency in maritime transport operations. Drawing on the relational network framework, the study examines their synergistic effects, particularly how strategic alliance intensity moderates digital capabilities, resilience mechanisms, and green compliance under fuel price volatility (in the Figure 1). A synthesis of maritime logistics literature validates their relevance, highlighting vulnerabilities in asset utilization and environmental adherence. This step fills a theoretical gap by contextualizing these factors within energy-intensive shipping environments and provides practitioners with a diagnostic tool for prioritizing alliance-driven improvements.

Figure 1. Factors Influencing Supply Chain Efficiency



Source: by the author.

Step 2: Evaluation and Analysis of Pre-Alliance Business Efficiency

Using financial metrics from corporate reports, this step establishes a baseline through input-output analysis of decision-making units representing individual maritime firms (in the Table 1). Inputs include total assets, cost of goods sold, and administrative expenses; sales revenue serves as throughput, with profit after tax as the key output (currency unit: USD 1,000).

Table 1. Data 2021-2025

DMUs	I1	I2	I3	O1	O1	Year
DMU1	105,188.59	37,181.70	4,058.97	54,528.05	18,801.46	2021
DMU2	42,466.02	20,256.56	804.14	31,284.70	7,811.60	2021
DMU3	125,100.52	49,396.90	3,139.96	72,487.08	15,852.96	2021
DMU4	410,913.27	79,073.33	11,296.19	122,764.69	27,608.65	2021
DMU5	208,232.82	30,978.36	7,198.93	52,536.86	34,041.74	2021
DMU6	219,567.30	223,434.81	6,126.75	244,380.62	23,779.44	2021
DMU7	233,697.11	55,829.98	7,007.47	87,497.61	26,689.64	2021
DMU8	68,351.52	26,689.64	3,522.88	41,317.25	9,151.83	2021
DMU9	123,798.58	47,520.58	3,254.83	74,899.48	2,1098.99	2021
DMU10	1,005,322.61	369,098.22	39,440.93	508,137.09	122,113.73	2021
DMU1	102,584.72	64,445.72	4,097.26	92,705.34	18,686.58	2022
DMU2	47,788.63	17,231.48	1,072.18	31,322.99	10,492.05	2022
DMU3	167,221.90	51,656.14	4,058.97	76,890.68	15,087.11	2022
DMU4	498,985.26	83,476.93	20,065.10	149,262.88	44,457.21	2022
DMU5	206,662.84	28,221.33	8,692.32	42,619.18	7,811.60	2022
DMU6	213,325.67	118,667.43	6,662.84	139,728.13	26,153.55	2022
DMU7	253,340.99	57,629.71	8,271.11	89,986.60	27,761.82	2022
DMU8	78,881.87	28,144.74	5,169.44	45,835.73	10,415.47	2022
DMU9	193,375.45	68,313.23	43,65.31	122,764.69	39,862.15	2022
DMU10	1,031,552.75	396,974.92	50,813.71	549,262.88	97,185.53	2022
DMU1	104,001.53	115,106.26	2,910.20	122,113.73	5,973.58	2023
DMU2	48,439.59	20,256.56	1,378.52	34,309.78	10,415.47	2023
DMU3	198,774.65	58,472.14	5,092.86	83,515.22	7,620.14	2023
DMU4	518,705.72	79,188.21	21,137.28	147,271.68	97,032.36	2023
DMU5	205,514.07	23,817.73	2,488.99	36,109.52	11,411.07	2023
DMU6	306,299.06	75,818.50	7,198.93	91,518.28	7,543.56	2023
DMU7	2,710,702.66	53,647.33	8,309.40	82,596.21	28,565.96	2023
DMU8	84,357.65	29,867.89	5,054.57	47,329.12	10,568.64	2023
DMU9	205,207.74	766,60.92	4,824.81	100,057.44	13,708.60	2023
DMU10	1,054,413.17	398,698.07	40,053.61	490,943.90	65,173.27	2023
DMU1	110,740.95	208,654.03	3,752.63	213,555.43	12,866.17	2024
DMU2	45,682.56	24,775.03	1,187.06	41,891.63	13,057.63	2024
DMU3	298,525.75	74,478.27	7,007.47	106,758.57	16,657.09	2024
DMU4	689,182.46	103,273.98	22,018.00	185,027.76	73,674.13	2024
DMU5	220,448.02	29,906.18	8,998.66	42,351.14	6,624.55	2024
DMU6	321,577.64	107,409.53	9,458.17	127,359.75	6,509.67	2024
DMU7	325,253.69	61,497.22	9,726.21	99,406.47	37,373.16	2024
DMU8	94,237.03	35,841.47	5,514.07	55,638.52	11,564.24	2024
DMU9	279,149.91	104,384.45	8,079.65	152,900.63	30,672.03	2024
DMU10	1,165,039.25	541,757.61	51,464.68	649,818.11	100,708.41	2024
DMU1	149,645.80	111,545.09	3,139.96	118,897.19	11,679.11	2025
DMU2	53,532.45	21,098.99	1,033.89	44,189.16	19,031.21	2025
DMU3	496,381.39	79,073.33	8,309.40	122,764.69	20,141.68	2025
DMU4	757,304.23	123,683.71	23,166.76	227,685.24	85,161.78	2025
DMU5	233,505.65	32,242.01	7,007.47	46,946.20	14,129.81	2025
DMU6	328,853.15	109,745.36	9,075.24	133,141.87	13,938.35	2025
DMU7	379,743.44	56,404.37	10,530.35	104,575.91	37,756.08	2025
DMU8	105,265.17	38,598.51	7,237.22	63,450.12	14,129.81	2025
DMU9	333,677.96	119,739.61	5,667.24	194,983.73	53,647.33	2025
DMU10	1,361,784.42	596,055.91	54,489.76	728,699.98	10,1321.08	2025

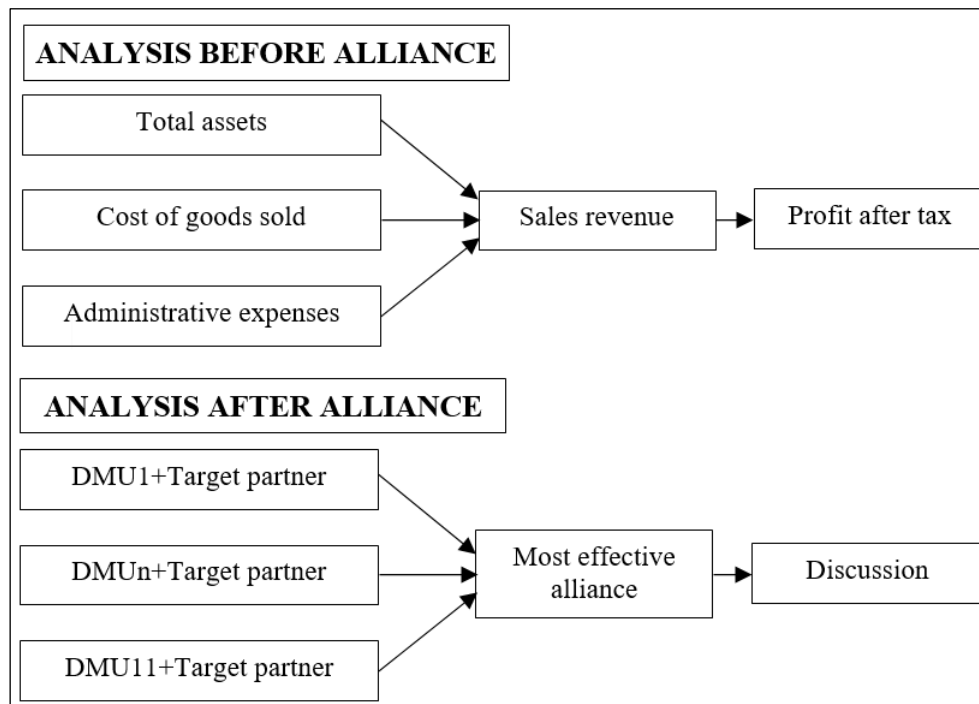
Source: Compiled by the author from the financial statements of the DMUs.

The analysis quantifies how escalating fuel costs inflate operating expenses and erode margins, exposing inefficiencies in supply chain coordination and risk management. By benchmarking pre-alliance performance, it generates counterfactual evidence essential for isolating alliance impacts, thereby strengthening causal inferences in strategic management research while guiding shipping executives toward targeted interventions.

Step 3: Selection of the Optimal Strategic Alliance and Results Discussion

Post-alliance scenarios are simulated by recombining decision-making units with prospective partners to evaluate efficiency frontiers. The most effective alliance is selected based on the highest post-alliance Super-SBM efficiency performance and the largest positive improvement in ranking relative to the focal DMU (in the Figure 2). Results are then discussed in terms of mechanisms (such as shared digital platforms for fuel optimization, coordinated asset deployment, and enhanced environmental compliance) that mitigate fuel-price risks.

Figure 2. Data Envelopment Analysis



Source: by the author.

This three-step process ensures methodological rigor and replicability, advancing alliance theory in dynamic logistics contexts while delivering prescriptive, implementable solutions for maritime enterprises facing sustained energy cost pressures.

3. Research Methodology

This study adopts a two-phase integrated quantitative approach that sequentially applies structural equation modelling to examine hypothesized interrelationships among antecedent constructs and super slack-based measure data envelopment analysis under variable returns to scale to benchmark and optimize strategic alliance configurations. The overarching relational network framework positions strategic alliance intensity as the central moderator linking five complementary capabilities (digital transformation capability, supply chain integration, supply chain resilience and risk management capability, green logistics and environmental compliance, and operational and asset management capability) to supply chain efficiency as the focal performance outcome. This dual-methodology design combines explanatory structural analysis with prescriptive efficiency-frontier analysis, thereby addressing critical theoretical gaps in maritime logistics while delivering actionable guidance for partner selection amid marine bunker fuel price volatility.

The integration of SEM and Super-SBM DEA is sequential and complementary rather than computationally embedded. SEM first identifies and quantifies the structural relationships between the hypothesized organizational capabilities and supply chain efficiency, thereby providing the explanatory basis for interpreting performance differences. Super-SBM DEA subsequently evaluates firm-level operational efficiency and simulated alliance configurations using financial input–output data. Accordingly, the SEM results inform the interpretation of the

efficiency patterns identified by DEA, while the DEA results provide an operational performance assessment of the strategic implications derived from the SEM analysis.

Structural Equation Modelling Phase: The first phase tests the theoretical nomological network through structural equation modelling. The SEM analysis used 385 valid responses from managers and professionals in Vietnam's maritime transportation and logistics sector, collected in March 2026. Respondents were recruited using convenience sampling, and a structured questionnaire was administered through online and in-person channels. After screening for completeness and response quality, 385 observations were retained for analysis. Measurement quality was evaluated using standardized factor loadings, composite reliability (CR), average variance extracted (AVE), and inter-construct correlations to assess discriminant validity. $CR \geq 0.70$ and $AVE \geq 0.50$ were adopted as the primary thresholds, while the standardized factor loadings reported in Table 2 provided item-level evidence of measurement quality. The measurement model is specified for each latent construct as $x_{ij} = \lambda_{ij}\xi_j + \delta_{ij}$ where x_{ij} denotes the observed indicator, λ_{ij} the factor loading, ξ_j the latent variable, and δ_{ij} the measurement error.

The structural model is formulated as:

$$SCE = \beta_1 SAI + \beta_2 DTC + \beta_3 SCI + \beta_4 SCR + \beta_5 GLE + \beta_6 OAC + \zeta \quad (1)$$

with additional mediation equations capturing indirect pathways (primarily through operational and asset management capability) and interaction terms to test the moderating role of strategic alliance intensity:

$$OAC = \gamma_1(SAI \times DTC) + \gamma_2(SAI \times GLE) + \dots + \zeta \quad (2)$$

Model identification follows standard covariance structure analysis. Parameter estimation employs maximum likelihood with robust standard errors. Overall model fit is evaluated against established thresholds for the $CMIN/DF < 3.0$, $CFI > 0.90$, $TLI > 0.90$, $RMSEA < 0.05$, $GFI \geq 0.90$, and $AGFI \geq 0.80$. Construct reliability and convergent validity were assessed using composite reliability (CR) and average variance extracted (AVE), while discriminant validity was examined from the inter-construct correlation structure.

Super Slack-Based Measure Data Envelopment Analysis Phase: The second phase benchmarks pre-alliance efficiency and simulates post-alliance performance. For each decision-making unit, inputs are total assets, cost of goods sold, and administrative expenses; sales revenue serves as intermediate throughput; and profit after tax constitutes the terminal output. Efficiency is measured using the input-oriented super slack-based measure model under variable returns to scale (Tone, 2002):

$$\rho^* = \min \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s} \sum_{r=1}^s \frac{s_r^+}{y_{r0}}} \quad (3)$$

$$\text{Subject to: } x_0 = X\lambda + s^- \quad (4)$$

$$y_0 = Y\lambda - s^+ \quad (5)$$

$$\sum_{j=1}^n \lambda_j = 1, \lambda_j \geq 0, s^- \geq 0, s^+ \geq 0, \quad (6)$$

$$\text{and } \lambda_0 = 0 \text{ (self-exclusion for super-efficiency scores exceeding unity).} \quad (7)$$

Post-alliance scenarios are generated by constructing virtual composite decision-making units that linearly combine the focal firm's inputs and outputs with those of prospective partners. The identical super slack-based measure model is reapplied to these synthetic units, enabling direct quantification of efficiency gains attributable to resource pooling, route optimization, and risk sharing.

The optimal alliance is defined as the virtual combination that achieves the strongest improvement in operational efficiency relative to the focal firm, as indicated jointly by its post-alliance Super-SBM efficiency score and the corresponding improvement in efficiency ranking. Candidate combinations are therefore compared on a common frontier, with preference given to the configuration that attains the highest efficiency score and the largest positive rank gain, while operational complementarity is used to support the economic interpretation of the selected partnership.

By rigorously separating explanatory pathway analysis from non-parametric frontier evaluation, this methodology advances methodological precision in transportation economics and supplies maritime executives with a transparent, replicable framework for evidence-based alliance formation that demonstrably mitigates fuel-cost shocks and enhances supply chain resilience.

4. Research Results

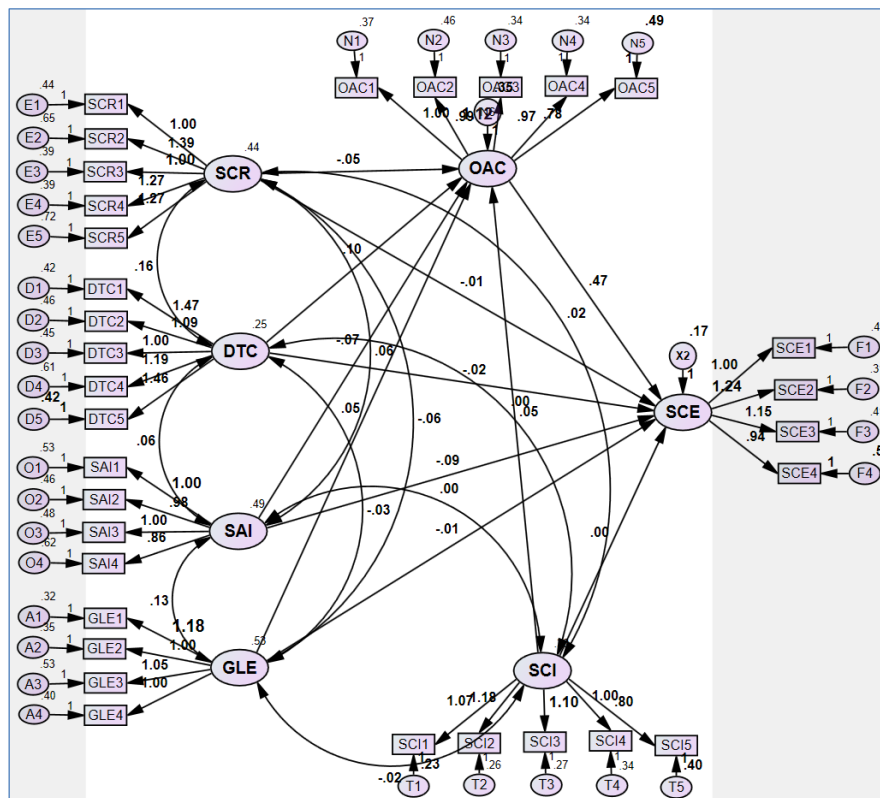
4.1 Modelling the Determinants of Supply Chain Efficiency in Shipping Companies: A SEM Approach

The structural equation modelling analysis was employed to rigorously test the hypothesized interrelationships among antecedent factors and supply chain efficiency in maritime transport enterprises. Evaluation of the measurement and structural models relied on multiple established goodness-of-fit indices, each assessed against widely accepted thresholds in the methodological literature (in the Figure 3).

The structural equation modelling analysis demonstrated excellent overall fit to the empirical data collected from maritime transport enterprises. The key goodness-of-fit indices: CMIN/DF = 1.586, CFI = 0.942, TLI = 0.935, RMSEA = 0.039, GFI = 0.900, and AGFI = 0.880, satisfy or exceed all established thresholds in the methodological literature (CMIN/DF < 3.0, CFI and TLI > 0.90, RMSEA < 0.05, GFI and AGFI ≥ 0.90 and ≥ 0.80 respectively). These results provide unequivocal confirmation that the proposed theoretical model offers a parsimonious, accurate, and reliable representation of the hypothesized relationships.

Operational and Asset Management Capability (OAC) exerts the strongest and most substantive direct positive effect on SCE ($\beta = 0.47$). This result underscores that continuous fleet modernization, highly efficient port operations and container repositioning, real-time data-driven scheduling, and consistently high asset utilization represent the dominant drivers of cost minimization, superior on-time delivery performance, rapid customer responsiveness, and enhanced resource productivity in sea freight operations. In a capital-intensive industry characterized by high fixed costs and volatile demand, superior operational capabilities directly translate into measurable efficiency gains.

Figure 3. Factors Influencing Supply Chain Efficiency Results



Source: Author's calculations.

In marked contrast, the direct effects of the remaining five constructs on SCE are weak to negligible (in the Table 2). The standardized path coefficients for Strategic Alliance Intensity (SAI), Digital Transformation Capability (DTC), Supply Chain Integration (SCI), Supply Chain Resilience & Risk Management Capability (SCR), and Green Logistics & Environmental Compliance (GLE) range between approximately -0.09 and 0.05, with several paths approaching zero. These modest direct influences indicate that participation in global vessel-sharing alliances, adoption of Industry 4.0 technologies, environmental compliance practices, and resilience mechanisms do not independently generate efficiency improvements once operational asset management is controlled for. The standardized measurement loadings were generally moderate to strong, and construct-level CR and AVE statistics

were evaluated jointly to establish internal consistency and convergent validity before interpretation of the structural paths.

Table 2. Standardized Regression Weights

			Estimate				Estimate				Estimate
OAC	←	SCR	-0.060	SAI2	←	SAI	0.710	OAC4	←	OAC	0.707
OAC	←	DTC	0.082	SAI1	←	SAI	0.692	GLE4	←	GLE	0.753
OAC	←	SAI	-0.085	DTC3	←	DTC	0.599	GLE3	←	GLE	0.723
OAC	←	GLE	0.061	DTC2	←	DTC	0.630	GLE2	←	GLE	0.773
OAC	←	SCI	0.055	DTC1	←	DTC	0.753	GLE1	←	GLE	0.834
SCE	←	SCR	-0.017	SCE1	←	SCE	0.584	DTC5	←	DTC	0.749
SCE	←	DTC	-0.024	SCE2	←	SCE	0.747	SCE4	←	SCE	0.543
SCE	←	SAI	-0.126	SCE3	←	SCE	0.666	SCI4	←	SCI	0.724
SCE	←	GLE	-0.008	OAC1	←	OAC	0.700	SCI3	←	SCI	0.796
SCE	←	SCI	0.004	OAC2	←	OAC	0.655	SCI2	←	SCI	0.818
SCE	←	OAC	0.470	OAC3	←	OAC	0.757	SCI1	←	SCI	0.809
SCR3	←	SCR	0.728	SCR4	←	SCR	0.802	OAC5	←	OAC	0.556
SCR2	←	SCR	0.750	SCR5	←	SCR	0.702	SCI5	←	SCI	0.614
SCR1	←	SCR	0.705	DTC4	←	DTC	0.611				
SAI3	←	SAI	0.711	SAI4	←	SAI	0.608				

Source: Author's calculations.

Nevertheless, the model reveals important mediation pathways. Notable inter-construct relationships, such as $GLE \rightarrow SCI$ (≈ 0.53), $SAI \rightarrow SCI$ (≈ 0.49), and $DTC \rightarrow SCR$ (≈ 0.44) suggest that strategic alliances, digital transformation, green practices, and resilience capabilities exert their primary influence on SCE indirectly by strengthening supply chain integration and, ultimately, operational asset management. This hierarchical structure aligns with the operational realities of maritime logistics, where technological, relational, and sustainability investments must be operationalized through optimized asset deployment and process synchronization to produce tangible efficiency outcomes.

From a theoretical perspective, these findings extend supply chain management theory to the maritime domain by demonstrating the pivotal mediating role of operational capabilities in translating upstream enablers into downstream performance. Practically, the results provide maritime enterprises with an evidence-based framework for identifying and selecting strategic cooperation partners. Potential allies should be evaluated primarily on their capacity to complement and elevate operational and asset management capabilities (through superior vessel-sharing arrangements that optimize fleet utilization, integrated digital platforms that enhance scheduling precision, or environmentally compliant technologies that integrate seamlessly into existing asset portfolios) thereby maximizing mutual gains in supply chain efficiency and long-term competitive resilience in global sea freight markets.

Table 3. Correlations

			Estimate
SCR	↔	DTC	0.480
SAI	↔	DTC	0.181
SAI	↔	GLE	0.262
GLE	↔	SCI	-0.044
SAI	↔	SCI	-0.008
DTC	↔	SCI	-0.016
SCR	↔	SCI	0.045
SCR	↔	SAI	0.131
DTC	↔	GLE	-0.091
SCR	↔	GLE	-0.126

Source: Author's calculations.

Standardized direct path coefficients to supply chain efficiency (SCE) reveal a clear hierarchy. Operational and Asset Management Capability (OAC) exerts the sole substantive positive direct effect ($\beta = 0.47$), indicating that fleet modernization, real-time scheduling, efficient container repositioning, and high asset utilization are the

dominant drivers of cost control, on-time performance, customer responsiveness, and resource productivity in capital-intensive sea freight operations.

In contrast, the direct effects of Strategic Alliance Intensity (SAI), Digital Transformation Capability (DTC), Supply Chain Integration (SCI), Supply Chain Resilience and Risk Management Capability (SCR), and Green Logistics and Environmental Compliance (GLE) are negligible (β ranging from -0.09 to 0.05). These constructs therefore contribute to SCE primarily through indirect pathways.

The inter-construct correlation matrix elucidates the underlying relational structure. The strongest linkage is between SCR and DTC ($\phi = 0.480$), underscoring that Industry 4.0 technologies (IoT, blockchain, end-to-end visibility) serve as critical enablers of resilience by supporting early risk detection and operational flexibility. Moderate positive correlations further highlight synergies: SAI $\leftrightarrow$ GLE ($\phi = 0.262$), SAI $\leftrightarrow$ DTC ($\phi = 0.181$), and SCR $\leftrightarrow$ SAI ($\phi = 0.131$). These associations demonstrate that strategic vessel-sharing alliances simultaneously promote green practices, digital adoption, and contingency capabilities. Weak or negative correlations (such as GLE $\leftrightarrow$ SCI (-0.044), SAI $\leftrightarrow$ SCI (-0.008), DTC $\leftrightarrow$ SCI (-0.016), DTC $\leftrightarrow$ GLE (-0.091), and SCR $\leftrightarrow$ GLE (-0.126)) indicate limited direct synergy among these pairs within the current sample (in the Table 3).

Collectively, the results establish a mediated causal hierarchy in which SAI, DTC, GLE, and SCR enhance SCE indirectly by reinforcing supply chain integration and, ultimately, operational asset management. Theoretically, this extends supply chain management literature to maritime logistics by positioning OAC as the pivotal mediator converting upstream enablers into downstream performance. Practically, the findings provide a precise framework for strategic partner selection: maritime enterprises should prioritize allies whose complementary strengths (superior vessel-sharing, integrated digital platforms, or seamless environmental compliance) directly elevate OAC, thereby amplifying efficiency gains, reducing transaction costs, and building long-term resilience in volatile global shipping markets.

4.2 Super-SBM-Oriented Result

Building on the structural relationships identified by SEM, the Super-SBM analysis evaluates whether these strategic implications are reflected in firm-level operational efficiency and potential alliance configurations. Pre-Alliance Analysis: In the capital-intensive maritime logistics sector (characterised by heterogeneous fleets, volatile freight rates, and fragmented route networks) the methodology provides an objective and robust assessment of operational efficiency (in the Table 4). The ranking results in 2025 reveal marked performance heterogeneity. DMU2 leads with the highest score of 1.5685, followed by DMU9 (1.4646) and DMU10 (1.42352). DMU10 demonstrates strong pre-alliance efficiency, reflecting effective management of its containerised cargo operations from its Hanoi base. In contrast, DMU8 ranks seventh with a substantially lower score of 0.54392, indicating considerable scope for productivity gains in resource utilisation and cost control.

Table 4. Rank and score pre-alliance

Rank	DMUs	Score
1	DMU2	1.65685
2	DMU9	1.46463
3	DMU10	1.42352
4	DMU1	1.31008
5	DMU4	1.24482
6	DMU7	0.93335
7	DMU8	0.54392
8	DMU5	0.38945
9	DMU3	0.25636
10	DMU6	-0.54096

Source: Author's calculations.

Post-Alliance Performance Analysis: Among the simulated partnerships involving DMU8, the DMU10+DMU8 combination emerges as the optimal configuration, achieving the highest post-alliance Super-SBM score (1.10124) and the largest improvement in efficiency ranking (Table 5). This result indicates that the combination offers the strongest potential for efficiency enhancement among the evaluated alternatives, while its operational complementarity further supports its strategic suitability for sea freight transportation.

Table 5. Virtual results

DMU	Score	Rank	DMU	Score	Rank
DMU2	1.65685	1	DMU7	0.93335	11
DMU9	1.31754	2	DMU7+DMU8	0.88957	12
DMU1	1.31008	3	DMU5+DMU8	0.56851	13
DMU10+DMU8	1.10124	4	DMU8	0.5143	14
DMU4+DMU8	1.09537	5	DMU3+DMU8	0.41829	15
DMU9+DMU8	1.08803	6	DMU5	0.38945	17
DMU4	1.05479	7	DMU3	0.25636	18
DMU2+DMU8	1.03523	8	DMU6+DMU8	0.20215	19
DMU1+DMU8	1.03047	9	DMU6	-0.56679	20
DMU10	1.01936	10			

Source: Author's calculations.

DMU10, a prominent Vietnamese enterprise headquartered in Hanoi in northern Vietnam, maintains a specialized focus on containerized cargo services along major regional and international routes. With an established fleet and infrastructure supporting Vietnam's export-driven economy, the enterprise has encountered persistent inefficiencies when operating in isolation. DMU8, based in Da Nang in central Vietnam, possesses extensive expertise in bulk cargo transportation, feeder services, and integrated port operations, underpinned by advanced supply chain coordination and a diversified network of strategic maritime corridors (in the Table 6). The geographical complementarity between these two locations constitutes a critical source of strategic advantage. Hanoi, situated in the densely industrialized Red River Delta, provides direct access to the northern gateway port of Hai Phong and proximity to the Chinese border, facilitating seamless connectivity with high-volume manufacturing hubs and cross-border trade corridors. In contrast, Da Nang, positioned midway along Vietnam's 3,260 Km coastline, operates as a premier deep-water port serving the central region, the Central Highlands, and key economic corridors linking to southern industrial zones. This north-central axis enables the alliance to create an integrated coastal network that spans Vietnam's primary economic poles without the fragmentation typical of standalone operators.

Table 6. Effective alliances

Virtual Combine	Target DMU8 Ranking (m)	Virtual Combination Ranking (n)	Difference (m)–(n)
DMU10+DMU8	14	4	10
DMU4+DMU8	14	5	9
DMU9+DMU8	14	6	8
DMU2+DMU8	14	8	6
DMU1+DMU8	14	9	5
DMU7+DMU8	14	12	2
DMU5+DMU8	14	13	1

Source: Author's calculations.

Considering the complementary business domains, forward-looking strategies, and pronounced geographical advantages of both enterprises, this alliance is poised to deliver significant synergistic outcomes and facilitate substantial market expansion. Upon formation, the partners can formulate policies to diversify service offerings, such as the integration of container and bulk transport solutions or the development of multimodal logistics capabilities. Moreover, the alliance enables access to a broadened customer base by merging their respective client portfolios and geographical strengths. In sea freight operations, the entities can share maritime assets (including vessels, terminal berths, and skilled crews) particularly when shipments align with mutually advantageous locations. Such resource integration stabilizes operational flows, shortens transit durations, minimizes empty repositioning voyages, and reduces key cost drivers such as fuel consumption, port dues, and maintenance expenditures. Consequently, the alliance fortifies the competitive positioning of the combined entity within both domestic and global maritime markets, thereby elevating overall business efficiency.

Table 7. Ineffective alliances

Virtual Combine	Target DMU8 Ranking (m)	Virtual Combination Ranking (n)	Difference (m)–(n)
DMU3+DMU8	14	15	(-1)
DMU6+DMU8	14	20	(-6)

Source: Author's calculations.

In addition to the alliances that yield favorable efficiency as presented in Table 6, there are alliances that exhibit non-positive efficiency (as shown in Table 7). These less efficient alliances do not encourage future cooperation.

5. Discussions

From a scientific perspective, the present analysis advances the methodological frontier of efficiency evaluation by extending the Super SBM-I-V model of DEA to the assessment of strategic alliances in capital-intensive maritime logistics. By constructing virtual decision-making units and quantifying post-alliance shifts in the efficiency frontier under variable returns to scale, the study furnishes robust empirical evidence of synergistic gains attributable to resource pooling and operational integration. This contribution enriches the literature in transportation economics and operations research, offering a replicable framework for modelling alliance-induced productivity enhancements in network industries where traditional parametric approaches often prove inadequate.

In practical terms, the findings furnish maritime transport executives and policymakers with a rigorous, data-driven instrument for partner selection amid the sector's inherent complexities. Enterprises confronting suboptimal fleet utilization, route fragmentation, or exposure to volatile freight markets can apply these insights to design collaborations that optimize vessel deployment, enhance service frequency, and strengthen resilience against supply chain disruptions. For DMU10, in particular, the alliance with DMU8 represents a feasible pathway toward operational revitalization, enabling the adoption of joint digital tracking systems, coordinated scheduling protocols, and shared risk-management strategies that elevate service reliability and customer satisfaction.

Economically, the alliance between DMU10 and DMU8 is anticipated to generate substantial value through pronounced economies of scale and scope that are uniquely amplified by the enterprises' geographical positioning. The north-central linkage allows for the establishment of efficient hub-and-spoke feeder networks between Hai Phong and Da Nang, dramatically improving vessel utilization rates and load factors while reducing the incidence of ballast voyages that plague independent operators. By consolidating operations across Vietnam's two most strategically vital maritime gateways, the alliance lowers unit transportation costs per twenty-foot equivalent unit through shared port infrastructure, joint bunkering agreements, and coordinated crew rotations, yielding direct savings in fuel, stevedoring, and terminal handling charges. Furthermore, the expanded route coverage enhances bargaining power with international shippers, port authorities, and fuel suppliers, thereby stabilizing revenue streams and mitigating exposure to global freight-rate volatility. In Vietnam's trade-dependent economy (where maritime transport accounts for over 90 percent of international cargo movement) this strategic integration not only augments profitability margins and return on invested capital but also fosters long-term sustainability by channeling savings into investments in energy-efficient vessels and green maritime technologies. Ultimately, the partnership enhances the enterprises' resilience within the competitive global shipping landscape while contributing measurably to national objectives of efficient trade facilitation, regional connectivity, and logistics sector development.

Taken together, the findings refine rather than replace prior evidence on strategic alliances, digitalization, resilience, and operational integration in maritime logistics. Consistent with earlier studies, the conceptual model suggests that these capabilities may function primarily as enabling conditions whose association with supply chain efficiency is realized through operational and asset management capability. This interpretation links the literature-based framework to the observed SEM structure, while the DEA results further indicate which alliance configurations may offer greater efficiency potential under the modeled conditions. Accordingly, the findings should be interpreted as evidence of theoretically consistent associations and simulated efficiency opportunities rather than as definitive proof of causal effects or realized post-alliance outcomes.

6. Conclusion and Further Research

The findings indicate that, within the present sample, operational and asset management capability exhibits the strongest substantive direct association with supply chain efficiency, whereas the remaining antecedent constructs are related to the outcome primarily through indirect pathways. By sequentially integrating structural equation modelling with input-oriented super slack-based measure data envelopment analysis under variable returns to scale, the research provides the first granular pre-post alliance efficiency decomposition grounded in audited

financial statements. The optimal configuration identified for 2025 pairs the Hanoi-based container specialist (DMU10) with the Da Nang-based bulk and feeder operator (DMU8), yielding the largest composite efficiency gain through geographical complementarity, shared asset utilization, and coordinated bunker procurement along Vietnam's north-central coastal corridor.

Theoretically, the findings advance strategic management and logistics scholarship by embedding strategic alliance intensity as the central moderator within a maritime-specific nomological network and by clarifying the hierarchical mediation structure that converts upstream relational, technological, and environmental capabilities into downstream performance via enhanced operational asset management. Methodologically, the extension of the super slack-based measure model to virtual composite decision-making units offers a replicable frontier-based protocol for alliance evaluation that overcomes the limitations of traditional parametric or aggregate-level approaches.

Practically, the study equips maritime executives and policymakers with a transparent, data-driven diagnostic toolkit for partner selection amid persistent marine bunker fuel volatility. The recommended alliance delivers measurable reductions in unit transportation costs, stabilization of freight rates, and accelerated adoption of low-carbon technologies, outcomes that directly support national objectives of trade facilitation, regional connectivity, and decarbonization in Vietnam's export-driven economy. In an era when maritime logistics forms the circulatory system of global commerce, the timely formation of such optimally calibrated strategic alliances emerges as an existential imperative for corporate resilience, macroeconomic stability, and sustainable international trade. Future research should extend the framework to multi-country panels and incorporate dynamic network data envelopment analysis to capture temporal alliance evolution under evolving geopolitical and regulatory conditions.

Despite its scientific and practical contributions, this study is subject to several limitations that should be acknowledged when interpreting the findings. First, the empirical analysis is confined to maritime transportation enterprises in Vietnam, which may limit the generalizability of the results to other institutional and market contexts. Second, the post-alliance efficiency estimates are derived from virtual composite DMUs rather than observed outcomes following actual alliance formation; therefore, they should be interpreted as indicative efficiency potential rather than definitive causal effects. Third, the SEM analysis captures relationships within the observed sample and period and may not fully account for dynamic changes arising from fuel-price volatility, regulatory shifts, or evolving alliance structures. Future research could address these limitations by employing larger cross-country samples, longitudinal data, and dynamic or network DEA models to further validate and extend the proposed framework.

Declarations

Declaration of Competing Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Use of Generative AI and AI-assisted Technologies: The author declares that no generative AI tools were used in the preparation of this manuscript.

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