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QUANTIFYING THE TRIPLE BOTTOM LINE IMPACT OF GEOPOLITICAL DISRUPTIONS ON MARITIME LOGISTICS

A Decision-Support Framework for Sustainable Supply Chains



Why Maritime Chokepoints Matter

Most EU trade moves by sea — and through a handful of fragile corridors

75.6%

of EU imports by weight
move by sea (2024)

73.7%

of EU exports by weight
move by sea (2024)

~12%

of global trade by volume
passed through Suez

>80%

of world trade volume
is carried by sea

The Strait of Malacca, the Strait of Hormuz, and the Bosphorus carry comparable shares of Europe–Asia flows. Two recent shocks exposed how a single-node failure cascades across the network.



The Research Gap

What current sustainable supply chain models still miss

1

Disruptions treated as local

Models read geopolitical shocks as exogenous, localized events — ignoring how a chokepoint perturbation propagates through a constrained network.

2

No link to all three TBL pillars

Metrics connecting propagation dynamics to economic, environmental, and social performance at once are missing.

3

Few integrated decision tools

Tools combining real-time geopolitical signals with hydrodynamic constraints and multi-objective optimization remain rare and mostly conceptual.



A Hybrid Decision-Support Model

Three modules feeding Triple Bottom Line outputs

Module 1

Hydrodynamic

Effective transit time per strait from a 1-D kinematic balance of vessel speed, current, wind, and waves.

Equation (1)

Module 2

Mason Signal Flow Graph

Propagates delays and cost amplification across the network; geopolitical risk enters as a perturbation term.

Equations (2)–(3)

Module 3

Multi-Objective Optimization

Selects routing and scheduling to minimize a weighted sum of cost, CO₂, and social risk.

Equation (4)



Triple Bottom Line outputs: Z_{cost} (economic) · Z_{CO_2} (environmental) · Z_{social} (social risk)



Applied to Two Documented Disruptions



Mapping the model onto real events (no computed results claimed)

Suez Canal Blockage

March 2021 · Ever Given

- Six-day closure of a single high-capacity edge.
- Lloyd's List valued halted traffic at ~9.6 billion USD per day.
- ~300 vessels queued at peak.
- Modeled by switching the Suez edge transmittance to zero (binary γ).

Red Sea Diversion

Nov 2023 → 2025 · Cape reroute

- Reroute added 10–14 days to Asia–Europe transit.
- CO₂ per voyage up 31% (N-Europe) and 66% (Mediterranean).
- ~13.6 Mt extra CO₂ in first four months (INVERTO/BCG).
- Modeled as a sustained, elevated geopolitical risk term.



Why It Matters in Practice

Implications across operators, policy, and finance

Logistics operators

A routing-decision tool wired to live AIS and geopolitical feeds; weights align routing with each carrier's ESG strategy.

Ports & policymakers

Propagation analysis flags critical nodes and guides redundancy investment; supports NIS2, CER, CSRD, and the 2023 IMO GHG Strategy.

Sustainable finance

Quantified TBL risk indicators feed ESG ratings and the pricing of green and sustainability-linked bonds.



Conclusions & Future Work

A conceptual contribution, with validation as the next step

Conclusions

- A hybrid model joins a hydrodynamic transit-time module, Mason signal flow graphs, and multi-objective optimization across the three TBL pillars.
- Demonstrated on the 2021 Suez blockage and the 2023–2025 Red Sea diversion.
- The contribution is conceptual; the mathematical structure and data sources are set out in full.

Future Work

- Calibrate with public AIS and trade data; validate numerically against PERT/CPM and shortest-path baselines.
- Run expert elicitation for the sensitivity parameter α .
- Extend to non-linear thresholds, dynamic weights, and congestion-recovery dynamics.
- Build an interactive digital-twin dashboard for scenario analysis.



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Thank you

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