MST-2025 Maritime Supply Chain New Trend Model: First Edition Quantitative Experimental Report Based on Sample HIN Data (including factual verification)

I. Port Perspective: "Losers" and "Winners" Amidst the Crisis

Based on the 2023–2024 container throughput (TEU) data from nodes_ports.csv, we calculated each port's absolute growth volume and growth rate. The results indicate that the direction and magnitude of these changes broadly align with publicly available statistics and news reports (e.g., Singapore Port's 2024 container throughput surpassed 40 million TEUs for the first time, representing approximately 5.4% growth compared to 2023 (Maritime and Port Authority of Singapore, 2025; PSA International, 2025; Chee, 2024; Reuters, 2025a), while Spain's Las Palmas and Barcelona recorded cargo volume increases of approximately 13% and 9% respectively in 2024 (Reuters, 2025b).

1. The Strong Growth Group (beneficiaries of new trends) includes:

(1) Port of Barcelona: 3.50 million → 3.93 million TEUs, representing a 12.29% increase. This aligns closely with reports indicating Spain's ports saw a 6% overall cargo growth post-Red Sea crisis, with Las Palmas and Barcelona recording 13% and 9% increases respectively (Reuters, 2025b).

(2) Port of Las Palmas: 1.20M → 1.32M TEU, representing a 10% increase. Reuters noted that Las Palmas emerged as a vital refuelling and resupply port for long-haul routes due to numerous vessels rerouting around the Cape of Good Hope, resulting in approximately 13% cargo volume growth (Reuters, 2025b).

(3) Port of Singapore: 39.01 million → 41.12 million TEU, representing a 5.41% increase. Data released by the Maritime and Port Authority of Singapore and PSA International confirmed that Singapore Port's container throughput reached approximately 41.12 million TEUs in 2024, representing a 5.4–5.5% increase from the 2023 figure of approximately 39.0 million TEUs (Maritime and Port Authority of Singapore, 2025; PSA International, 2025; Chee, 2024; Reuters, 2025a).

(4) Port of Shanghai: 49 million → 51 million TEUs, representing a 4.08% increase. Data from both the World Bank and UNCTAD indicate that Shanghai maintained its position as the world's largest container port in 2023–2024, with stable throughput growth. A growth rate of approximately 4% falls within a reasonable range for publicly available statistics (UNCTAD, 2024b; World Bank, 2025).

(5) Port of Rotterdam: 13.4 million → 13.8 million TEU, representing a 2.99% increase. Statistics from the Port of Rotterdam Authority and relevant EU sources indicate a moderate recovery in Rotterdam's container operations during 2023–2024, with low single-digit growth rates aligning with our projected trajectory (Port of Rotterdam Authority, 2024; UNCTAD, 2024b).

2. The significantly impacted group (the first casualties of the "core corridor disruption") includes:

(1) Port of Jeddah: 6.5 million → 4.0 million TEUs, a 38.46% decline. Multiple independent analyses indicate the Red Sea crisis has led to a substantial reduction in deep-sea vessel calls at Jeddah: Sea-

Intelligence statistics show deep-sea port calls in the Red Sea declined by approximately 85% below normal levels in the first half of 2024 (Sea-Intelligence, 2024). Port economics research further highlights Jeddah and King Abdullah as among the most severely impacted ports (Notteboom & Haralambides, 2024; Asia Cargo News, 2024).

(2) Sokhna Port: 0.9 million → 0.5 million TEUs, a decrease of 44.44%. Whilst public literature more frequently discusses impacts at the level of "the Suez Canal and Egypt's overall port system," the Red Sea crisis and the approximately 50–70% reduction in Suez Canal throughput have been explicitly confirmed by UNCTAD and the IMF (UNCTAD, 2024a; UNCTAD, 2024b; IMF, 2024; Associated Press, 2024a). A channelling contraction of this magnitude sufficiently supports our designation of Sohna as an example of a highly exposed port.

Overall, Singapore, Shanghai, and Rotterdam maintained their structural status as "super hub ports," sustaining positive growth amid global shocks. This aligns with the World Bank's analysis in the Container Port Performance Index 2020–2024, which highlighted Singapore's continued high efficiency during severe scheduling disruptions (World Bank, 2025), demonstrating such hub ports possess greater route diversity and substitution capacity. In contrast, Jeddah and Sohna, heavily reliant on the Suez-Red Sea corridor, experienced throughput collapse, exemplifying highly exposed port nodes (Notteboom & Haralambides, 2024; OceanMind, 2025). Spain's Las Palmas and Barcelona, meanwhile, gained diversional traffic dividends amid the Red Sea crisis, being regarded by Reuters and industry analysis as "crisis-driven new transhipment hubs" (Reuters, 2025b; UNCTAD, 2024b).

II. Key Channels and Major Routing: Structural Rearrangement of CHN→EU Trunk Traffic

Based on aggregated traffic data for "China→Europe (CHN→EU)" from edges_vessel_chokepoint.csv, we compared channel structures between 2023 (pre-crisis) and 2024 (post-crisis). This comparison aligns closely with UNCTAD's diagnosis of traffic redistribution between the Suez Canal and Cape Route: UNCTAD noted that by mid-2024, vessel tonnage transiting Suez had declined by approximately 70%, while arrivals via the Cape Route increased by roughly 89%, with container vessel ton-mile demand rising by approximately 12% (UNCTAD, 2024b; UNCTAD, 2024c).

1. 2023: Suez Canal (SUEZ) as sole primary route

We assume the 2023 CHN→EU route primarily via SUEZ: (1) DWT approximately 450 million tonnes; (2) TEU approximately 22 million; (3) average voyage duration approximately 25 days; (4) no significant rerouting (rerouted_flag = 0). Whilst the specific figures are illustrative, this structure of "high dependence on the single Suez channel" aligns with assessments by organisations such as UNCTAD and the Atlantic Council that "Suez handles approximately 10% of global freight volume and 22–30% of container trade" (UNCTAD, 2024b; UNCTAD, 2024c; Atlantic Council, 2025; Safety4Sea, 2024; Majalla, 2023).

2. 2024: The New Landscape Following the Red Sea Crisis

(1) Via Suez Canal: DWT approximately 180 million tonnes, TEU approximately 8 million, volume roughly one-third of the base period, marked as rerouted status (rerouted_flag = 1).

(2) Via Cape of Good Hope (CGH): Additional DWT approx. 320 million tonnes, TEU approx. 14 million, with average voyage duration extended to approx. 33 days.

UNCTAD's Rapid Assessment and Review of Maritime Transport 2024 indicate that since November 2023, most east-west trunk routes have shifted via the Cape of Good Hope. Vessel tonnage transiting the Suez Canal and Gulf of Aden has declined by 50–76%, while Cape of Good Hope arrivals have surged by nearly 90%, concurrently increasing voyage durations and fuel consumption substantially. (UNCTAD, 2024a; UNCTAD, 2024b; UNCTAD, 2024c; UNCTAD, 2024d). The IMF similarly documented the substantial decline in transit volumes and global trade resulting from Red Sea attacks (IMF, 2024). Consequently, the report's characterisation of the 2024 structure as a shift from a single Suez Canal route to a dual-channel system of "Suez + Cape of Good Hope (CGH)" with inverted weightings constitutes an abstraction highly consistent with authoritative factual assessments.

III. Channel Shock and Exposure Index: Differentiated Impacts on Ports and Nations

Using edges_chokepoint_country_impact.csv and edges_event_chokepoint.csv, we constructed a simplified "Channel Shock Exposure Index" for ports and nations. Methodologically, this aligns with UNCTAD's analytical framework for "global maritime chokepoint vulnerability": UNCTAD notes that by mid-2024, traffic through the Panama and Suez Canals had declined by over 50% from peak levels, becoming a key source of supply chain vulnerability (UNCTAD, 2024b; UNCTAD, 2024e). In the sample data, the following observations emerge:

1. High exposure end:

(1) Port of Jeddah, Port of Sokhna, and Egypt as a whole (COUNTRY=EGY) experienced negative impacts ranging from -35% to -50% due to the combined effects of SUEZ and Bab el-Mandeb. UNCTAD, IMF, and AP statistics indicate that both transit volume and revenue through the Suez Canal halved in 2024: vessel transits decreased by 50%, while revenue fell from approximately US$10.25 billion to around US$3.99 billion (UNCTAD, 2024a; UNCTAD, 2024b; IMF, 2024; Associated Press, 2024a), aligning with the high vulnerability setting for Egypt and its ports in our exposure index.

(2) The United States has been impacted by a reduction in transit capacity of approximately -32% due to the drought in Panama. Analysis from the IMF and industry sources indicates that the Panama Canal's daily transit capacity decreased from 36 vessels to 22 vessels during 2023–2024 due to extreme drought conditions, resulting in a year-on-year decline in transit trade volume of approximately 29–32% (Panama Canal Authority, 2024; IMF, 2024; Seatrade Maritime, 2024; Resilinc, 2023; Reuters, 2023; Max Security, 2024).

2. Positive beneficiaries:

(1) Ports of Las Palmas and Barcelona gained approximately 13% and 9% tonnage growth respectively from the positive impact of the Cape of Good Hope (CGH) alternative route; This has been corroborated by Reuters' reporting on Spanish port traffic for 2024 (Reuters, 2025b) and cited by UNCTAD as a prototypical case of "detouring enabling certain alternative ports to emerge as new transhipment hubs" (UNCTAD, 2024b).

This structural pattern of "impact-exposure-redistribution" is further supported by PortEconomics and OceanMind's studies on port impacts during the Red Sea crisis: The former noted a substantial decline in deep-sea port calls at the Red Sea and Gulf of Aden in 2024, while the latter, using Jeddah as an example, demonstrated a sustained downward trajectory in monthly cargo volumes between 2023 and 2024 (Notteboom & Haralambides, 2024; OceanMind, 2025; Sea-Intelligence, 2024). Consequently, our modelling abstraction within the MST-2025 framework—constructing indicators for "structural vulnerability" and "structural benefit" by weighting the absolute impact values of each port/nation across different chokepoints—is grounded in factual evidence.

IV. Preliminary Profile of Emerging Trends in MST-2025 Based on Sample Data (Benchmarking Against Real-World Data)

Integrating the aforementioned port, corridor, and vulnerability analyses, this round of quantitative experimentation using sample CSV data has yielded a preliminary "trend typology prototype" for the MST-2025 maritime supply chain model. These trends align closely with authoritative global assessments of real-world pattern evolution for 2023–2025:

1. Trend One: Decentralisation of Main Shipping Routes and Emergence of South Atlantic–Indian Ocean "Alternative Corridors"

Within China–EU deep-sea container flows, the sample data shows TEU volumes via the Suez Canal declining from approximately 22 million to 8 million, while those via the Cape of Good Hope rise from near zero to around 14 million. This abstractly illustrates "the gradual shift of trunk traffic from reliance on a single chokepoint towards multi-channel redundancy." UNCTAD data indicates that following the Red Sea crisis, vessel tonnage capacity via the Suez Canal and Gulf of Aden declined by approximately 70–76%, while Cape of Good Hope arrivals increased by around 89%. Global vessel ton-mile demand grew by 3%, with container vessel demand rising by 12% (UNCTAD, 2024b; UNCTAD, 2024c). The ITF/OECD thematic report further indicates that freight rates surged by approximately 130% between November 2023 and March 2024, reflecting the cost implications of delays and detours (ITF/OECD, 2024).

2. Trend Two: Traditional Red Sea Hub Ports "Severely Affected", Mediterranean Peripheral Ports "Passively Upgraded"

Ports such as Jeddah and Sohna, heavily reliant on the Suez-Red Sea corridor, experienced a collapse in throughput of 35–45% within a short period in the sample data; In reality, studies similarly indicate Jeddah and King Abdullah as the "hardest-hit" ports in the Red Sea crisis, experiencing "double-digit or greater declines" in deep-sea port calls (Notteboom & Haralambides, 2024; Asia Cargo News, 2024; Sea-Intelligence, 2024; OceanMind, 2025). Concurrently, Barcelona and Las Palmas achieved significant growth through diversion traffic. The 9% and 13% growth rates reported by Reuters confirm the rationale for designating them as "emerging hubs" within our HIN model (Reuters, 2025b).

3. Trend Three: Enhanced Shock-Absorption Capacity of Super Hub Ports

Singapore, Shanghai, and Rotterdam maintained 3–5% growth during the disruption. The World Bank's Container Port Performance Index 2020–2024 specifically cites Singapore as a case study, demonstrating its sustained high efficiency and service levels amid global schedule disruptions triggered by the Red Sea crisis (World Bank, 2025). Singaporean authorities and media also reported record-high container throughput and fuel sales in 2024 (Maritime and Port Authority of Singapore, 2025; Chee, 2024; Reuters, 2025a). This provides factual grounding for designing the "Resilience Index" within the MST-2025 model.

4. Trend Four: Climate and Carbon Policy Coupling Forms a Three-Dimensional Constraint of "Cost–Path–Emissions"

Beyond the Red Sea and Panama Canal disruptions, the EU Emissions Trading System (EU ETS) formally incorporated shipping into its carbon market from 2024, covering CO_2 emissions from vessels over 5,000 gross tonnes entering or leaving EU ports, with plans to progressively expand coverage (European Commission, 2024; ICAP, 2024). Concurrently, the IMO is advancing a global GHG charging mechanism and fuel standards for adoption in 2025, with plans to implement a $100 per tonne charge on excess emissions from 2027 onwards, providing a price signal for global shipping emissions reductions (Associated Press, 2025). UNCTAD scenario analysis indicates that Red Sea detours have increased greenhouse gas emissions by up to 70% for certain voyages, particularly on the Singapore–Rotterdam round trip route (UNCTAD, 2024d). These findings support the report's modelling proposition that "marginal weighting must expand from a single time/distance metric to a comprehensive time–cost–emissions weighting".

V. Conclusion: Alignment of This Experiment with Real-World Conditions

In summary, although this report employs an exemplary HIN dataset, the four major trends identified—(1) the decentralisation of east-west trunk routes and the emergence of alternative Cape of Good Hope corridors; (2) the severe impact on traditional Red Sea hub ports and the passive upgrading of Mediterranean peripheral ports; (3) the shock-absorbing capacity of super hub ports under stress; (4) The convergence of Red Sea, Panama Canal, EU ETS, and IMO emissions reduction policies forming a three-dimensional constraint of "cost-path-emissions"—all find clear factual support in reports from UNCTAD, IMF, World Bank, EU, and mainstream industry sources (UNCTAD, 2024a, 2024b, 2024c, 2024d, 2024e; IMF, 2024; World Bank, 2025; European Commission, 2024; ICAP, 2024). Consequently, the MST-2025 experimental results may be regarded as an abstract model highly aligned with the real world in terms of "structure and direction".

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