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Predictive Models for Port Disruption and Resilience

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Abstract

Port disruptions impose disproportionate costs on global trade relative to the frequency with which they occur, reflecting the concentration of throughput at a small number of strategically critical nodes and the limited redundancy available in global routing networks. This monograph develops a predictive framework for port disruption risk assessment, drawing on historical incident data, infrastructure vulnerability indicators, and geopolitical risk modeling. The framework is designed for operational use by logistics continuity planners in both government and private sector contexts and has been validated against a retrospective dataset of 187 documented port disruption events across six regional corridors between 2015 and 2023. Policy implications and recommendations for allied coordination are discussed in the concluding section.

1. Introduction

The global logistics system is characterized by a fundamental tension between efficiency and resilience. Decades of optimization toward lean, just-in-time supply chain models have concentrated throughput at a decreasing number of high-capacity nodes, reducing per-unit logistics costs while simultaneously increasing systemic exposure to disruption at those nodes. The result is a network in which a relatively small number of disruption events — concentrated at chokepoints and high-volume terminals — account for a disproportionate share of total disruption costs.

This concentration creates both analytical and policy challenges. Analytically, the rarity of major disruption events at any given node makes purely statistical prediction difficult — the historical record is too thin to support actuarial approaches at the node level. Policymakers, meanwhile, face the challenge of allocating resilience investment across a large and heterogeneous set of nodes without reliable estimates of relative risk.

This monograph addresses both challenges through a predictive framework that integrates structural vulnerability indicators — which can be assessed independently of historical disruption frequency — with geopolitical risk modeling and historical incident patterns at the corridor level. The framework produces node-level risk scores that are robust to thin historical data and are updated dynamically as underlying conditions change.

2. Conceptual Framework

The predictive framework developed here rests on a distinction between two categories of disruption risk: structural risk and dynamic risk. Structural risk reflects the physical and operational characteristics of a node that make it inherently more or less vulnerable to disruption — berth capacity, crane redundancy, landside connectivity, and digital systems architecture. These characteristics change slowly and can be assessed through infrastructure analysis independent of recent disruption history.

Dynamic risk reflects the current geopolitical, meteorological, and operational environment in which the node operates — territorial disputes, labor tensions, extreme weather exposure, and the threat posture of adversarial state and non-state actors. Dynamic risk indicators change rapidly and require continuous monitoring to be operationally useful.

The framework combines structural and dynamic risk scores through a weighted composite index, with weights calibrated against the retrospective disruption dataset. The composite index is designed to be interpretable by non-technical users while preserving the dimensional detail needed for technical analysis.

2.1 Structural Risk Indicators

Berth Capacity and Redundancy. Nodes with limited berth capacity relative to throughput demand are more vulnerable to disruption from equipment failures, vessel incidents, or labor actions that reduce available berth time.

Crane and Equipment Redundancy. Terminal operating capacity is a function not only of berth availability but of crane and equipment density. Nodes with low crane-to-berth ratios have limited ability to compensate for equipment outages.

Landside Connectivity. Port disruptions frequently propagate through landside networks — road, rail, and inland waterway — that have insufficient capacity to handle throughput rerouting. Nodes with limited landside alternatives present elevated total disruption risk.

Digital Systems Architecture. Terminal operating systems, gate automation, and cargo management platforms present an expanding attack surface. Nodes operating legacy systems with limited network segmentation present elevated cyber disruption risk.

2.2 Dynamic Risk Indicators

Geopolitical Exposure. Proximity to territorial disputes, sanctions regimes, and adversarial state activity creates dynamic disruption risk that is not captured by structural indicators alone.

Labor Relations. Port labor actions have historically been among the most frequent causes of major disruption events in North American and European corridors. Labor relation indicators — contract expiration timelines, historical strike frequency, and regulatory environment — are incorporated as dynamic risk factors.

Weather and Sea State. Seasonal weather patterns, tropical cyclone exposure, and sea state variability create predictable dynamic risk profiles for nodes in affected corridors.

Threat Actor Posture. Assessed threat actor interest in specific nodes, derived from PLIANT's Atlas Intelligence Database incident records and partner-shared intelligence, is incorporated as a dynamic risk modifier for nodes in high-threat corridors.

3. Data and Methodology

The retrospective validation dataset comprises 187 documented port disruption events occurring between January 2015 and December 2023 across six regional corridor systems: North Atlantic, Asia-Pacific, Middle East/Indian

Ocean, Mediterranean, South American Atlantic, and trans-Pacific. Events were drawn from trade press records, port authority incident reports, Lloyd's List Intelligence, and PLIANT Atlas database records. Disruption severity was classified on a five-point scale based on throughput impact and duration.

Structural risk indicators were coded for each node in the dataset using a standardized rubric developed through iterative expert consultation with port operators, logistics planners, and infrastructure security specialists. Dynamic risk indicators were coded retrospectively for the period of each disruption event using contemporaneous records where available and reconstructed assessments where primary records were unavailable.

Model validation followed a leave-one-out cross-validation procedure at the corridor level — the model was trained on five corridors and validated on the sixth, repeated for each corridor. This approach guards against overfitting to corridor-specific disruption patterns while preserving the full dataset for final model calibration.

4. Findings

The composite risk index achieves a disruption prediction accuracy of 74.2% at the node level across the retrospective validation dataset, representing a 21-point improvement over a baseline model using throughput volume alone as a risk proxy. Structural risk indicators account for 58% of total model explanatory power, reflecting the importance of infrastructure characteristics as a foundation for disruption risk assessment. Dynamic risk indicators account for the remaining 42%, with geopolitical exposure and labor relations as the strongest dynamic predictors.

> **High-severity disruption events — those in the top quintile of throughput impact — are predicted with substantially higher accuracy (81.3%) than low-severity events (68.7%), reflecting the stronger signal provided by the combination of structural vulnerability and dynamic threat exposure for the most consequential disruption scenarios. This asymmetry is operationally advantageous: the model is most reliable precisely for the events that matter most to continuity planners.**

Regional performance varies significantly. Asia-Pacific corridor nodes achieve the highest prediction accuracy (79.1%), driven by the depth of Atlas database coverage for APAC nodes and the relative stability of structural risk profiles in the region. South American Atlantic corridor nodes present the lowest accuracy (67.3%), reflecting data limitations and the high variability of labor relations dynamics in the corridor.

5. Policy Implications

The predictive framework developed here has several direct policy implications for allied logistics continuity planning and infrastructure investment prioritization.

First, resilience investment should be concentrated at nodes where structural risk scores are highest and dynamic risk exposure is elevated — the intersection of inherent vulnerability and current threat environment. Nodes that score high on structural risk but low on dynamic exposure represent a lower near-term priority, though they warrant monitoring as geopolitical conditions evolve.

Second, the model's strong performance on high-severity events suggests that continuity planners can use the composite index with reasonable confidence for scenario planning purposes involving major disruption events. Lower-severity disruption planning should supplement the model with node-specific operational intelligence not fully captured by the indicator set.

Third, the data limitations identified for several regional corridors — particularly South American Atlantic and sub-Saharan African nodes — represent a priority gap for allied intelligence collection and sharing. The model's performance in these corridors will improve substantially as Atlas database coverage is extended.

6. Conclusion

Port disruption risk is predictable to a meaningful degree when structural vulnerability indicators are combined with dynamic geopolitical and operational risk factors. The framework developed in this monograph provides a practical tool for logistics continuity planners that is robust to thin historical data and updatable as conditions change. Ongoing development priorities include extending Atlas database coverage to under-assessed regional corridors, integrating real-time dynamic risk feeds for surge update capability, and developing a public-facing version of the framework for use by commercial logistics operators outside PLIANT's credentialed partner network.

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