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Supply Chain Resilience and Port Congestion: Insights from U.S. Port Operations

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Abstract

Global supply chains rely heavily on the efficient functioning of seaports, which serve as critical gateways linking maritime transportation with inland logistics networks. Port congestion disrupts these flows by increasing vessel turnaround times, reducing schedule reliability, and amplifying delays across upstream and downstream supply chain activities. In recent years, global disruptions have exposed structural vulnerabilities in port operations, raising important questions about supply chain resilience and the ability of logistics systems to adapt under sustained stress. This study examines the evolution of port congestion in U.S. ports by comparing vessel turnaround performance before and after major global disruptions, using 2019 as a pre-disruption benchmark and 2023 as a post-disruption observation year.

The analysis is based exclusively on data obtained from the UNCTAD Port Calls database, which provides standardized indicators on vessel activity and median time spent in port. Median turnaround time is employed as the primary measure of congestion, as it offers a robust representation of typical port performance while limiting the influence of extreme outliers. The findings reveal that overall port congestion in U.S. ports increased between 2019 and 2023, with median time spent in port rising for most vessel categories. This indicates that port performance in 2023 had not fully returned to pre-disruption efficiency levels. However, the magnitude and direction of congestion changes varied significantly across vessel types. Dry bulk carriers experienced the most pronounced deterioration in turnaround times, suggesting structural constraints and limited operational flexibility in bulk-handling supply chains. Container ships and liquid bulk carriers showed more moderate increases, reflecting comparatively higher levels of operational maturity, technological integration, and coordination within these segments. LNG carriers exhibited moderate deterioration, while LPG carriers emerged as a notable exception, demonstrating an improvement in median turnaround time relative to 2019.

From a supply chain management perspective, these results highlight the uneven nature of resilience across maritime logistics segments. Supply chains optimized primarily for efficiency under stable conditions prior to 2019 appear to have struggled to adapt to prolonged uncertainty and variability by 2023. In contrast, segments characterized by standardized processes, dedicated infrastructure, or adaptive operational practices exhibited greater resilience or even performance improvement. Overall, this research contributes to the understanding of supply chain resilience by demonstrating how changes in port congestion reflect deeper structural characteristics of maritime logistics systems.

Introduction

In an increasing globalized economy, supply chains have become more complex, geographically dispersed, and interdependent. Firms today rely on tightly coordinated networks of suppliers, manufacturers, logistics providers, and distributors to deliver goods efficiently and reliably to markets around the world. At the centre of these networks lies transportation infrastructure, which enables the physical movement of goods across borders and regions. Among all transportation modes, maritime transport plays a particularly vital role, accounting for the majority of global trade by volume. Seaports, as the interface between maritime and inland transportation systems, therefore represent critical nodes within global supply chains. The efficiency and reliability of port operations directly influence supply chain performance, cost structures, and resilience.

Supply chain management (SCM) has traditionally emphasized efficiency, cost reduction, and speed. For several decades prior to 2019, many firms adopted lean and just-in-time strategies, minimizing inventory buffers and relying on predictable transportation schedules. Ports during this period were largely optimized for throughput efficiency, focusing on reducing vessel dwell time, maximizing asset utilization, and handling steadily growing trade volumes. Under relatively stable global trade conditions, this efficiency-driven model delivered significant benefits, including lower logistics costs and faster response times. However, it also reduced slack and redundancy within supply chains, leaving them more vulnerable to large-scale disruptions.

Port congestion represents one of the most visible and impactful manifestations of supply chain stress. Congestion occurs when the demand for port services exceeds available capacity, resulting in vessel queues, longer waiting times at anchorages, extended cargo handling durations, and delayed vessel departures. From a supply chain perspective, port congestion is not merely a localized operational problem; it has system-wide implications. Delays at ports propagate upstream and downstream, disrupting production schedules, increasing inventory holding requirements, reducing service reliability, and elevating transportation and demurrage costs. As ports serve multiple supply chains simultaneously, congestion at major gateways can affect a wide range of industries, including manufacturing, energy, agriculture, and retail.

The global disruptions that unfolded after 2019 exposed the fragility of efficiency-focused supply chain designs. Sudden shifts in demand patterns, labour shortages, capacity imbalances, and operational constraints placed unprecedented pressure on ports and logistics systems worldwide. Even as trade volumes recovered, many ports struggled to restore pre-disruption levels of performance. These challenges brought renewed attention to the concept of supply chain resilience, defined as the ability of a supply chain to absorb shocks, adapt to changing conditions, and recover performance within an acceptable timeframe. In this context, port congestion has emerged as a key indicator of resilience, reflecting how well maritime and logistics systems can cope with sustained stress.

Understanding port congestion through a supply chain lens requires moving beyond aggregate measures and examining performance across different segments of maritime operations. Different vessel types and cargo categories interact with port infrastructure in distinct ways. Container ships, dry bulk carriers, liquid bulk carriers, and gas carriers rely on different handling processes, equipment, and coordination mechanisms. As a result, congestion impacts and recovery trajectories may vary significantly across vessel categories. A disaggregated analysis can therefore provide more nuanced insights into where vulnerabilities are concentrated and where resilience mechanisms are most effective.

This study focuses on U.S. ports, which play a central role in global and regional supply chains. The United States is one of the world's largest trading nations, with ports handling vast volumes of imports and exports that support domestic consumption and industrial production. Congestion at U.S. ports has far-reaching implications, affecting not only international trade partners but also inland transportation networks, distribution centres, and end markets across the country. Analysing congestion trends in U.S. ports thus offers valuable insights into broader supply chain dynamics and resilience challenges.

The objective of this research is to assess changes in port congestion in U.S. ports by comparing vessel turnaround performance before and after major global disruptions. The study uses 2019 as a pre-disruption baseline year and 2023 as a post-disruption observation year. By examining median time spent in port across major vessel categories, the analysis seeks to identify how congestion levels evolved over time and how different segments of maritime supply chains responded to sustained operational pressure. Median turnaround time is employed as the primary indicator because it provides a robust measure of typical port performance while limiting the influence of extreme outliers that may distort average values.

The data used in this study are obtained from the UNCTAD Port Calls database, which provides standardized and internationally comparable indicators on vessel activity and time spent in port. Using a single, authoritative data source ensures consistency and reliability in measurement while allowing for meaningful comparison across vessel types and time periods. The focus on vessel-level indicators enables a direct assessment of operational performance at ports, which is closely linked to supply chain efficiency and reliability. Investments in efficiency-enhancing technologies and infrastructure can improve throughput under normal conditions, but without sufficient flexibility and redundancy, such systems may struggle to adapt to sudden changes in demand or operating constraints. By examining changes in port congestion over time, this study contributes to understanding how this trade-off has played out in practice within U.S. port operations.

The comparison between 2019 and 2023 also reflects a broader shift in supply chain priorities. Prior to 2019, many firms relied on historical performance data and stable trade patterns to guide logistics planning. By 2023, supply chain managers were operating in a more uncertain environment, placing greater emphasis on risk mitigation, flexibility, and contingency planning. Ports, in turn, faced pressure to adapt their operations to support these evolving needs. Analysing congestion outcomes across vessel categories provides insight into the extent to which port systems were able to adjust to this new reality.

This research makes several important contributions. First, it provides an empirical assessment of port congestion trends in U.S. ports using a consistent and transparent data source. Second, by disaggregating performance by vessel type, it highlights differences in congestion outcomes and resilience across maritime supply chain segments. Third, it integrates port performance analysis with supply chain management theory, emphasizing the implications of congestion for lead time reliability, inventory planning, and overall supply chain performance. Finally, the study offers a foundation for managerial and policy discussions on how ports and supply chain stakeholders can strengthen resilience in the face of future disruptions.

The remainder of this paper is structured as follows. The next section reviews relevant literature on supply chain management, port congestion, and resilience. This is followed by a description of the data and methodology used in the analysis. The data analysis section presents empirical findings on changes in port congestion between 2019 and 2023, supported by tables and figures. The discussion section interprets these findings from a supply chain resilience perspective and outlines managerial implications. The paper concludes by summarizing key insights, acknowledging limitations, and suggesting directions for future research.

Literature Review

Christopher & Peck (2004) – "Building the Resilient Supply Chain"

Christopher and Peck's work is widely cited as an early foundation for modern supply chain resilience thinking. The authors argue that as supply chains became leaner, more global, and more outsourced, they also became more vulnerable to disruptions. The 2019 vs 2023 comparison can be interpreted through their lens as a shift from an efficiency-dominant operating logic (pre-2019) toward an environment where resilience capability becomes essential (2023). Overall, the paper supports the argument that persistent congestion is not merely operational—it reflects structural resilience limitations across the supply chain.

Pettit, Fiksel, & Croxton (2010) – Supply Chain Resilience Framework

Pettit, Fiksel, and Croxton propose a structured resilience framework that links vulnerabilities (e.g., turbulence, capacity constraints, external pressures) with capabilities (e.g., flexibility, redundancy, collaboration, visibility). This framework maps neatly to port congestion analysis because ports represent capacity-constrained, multi-stakeholder systems where vulnerabilities (labor, infrastructure, surges in arrivals, inland bottlenecks) increase the likelihood of delay. The framework also helps justify why an analysis should be disaggregated by vessel category rather than only "all ships."

Tang (2006) – Robust Strategies for Mitigating Supply Chain Disruptions

Tang differentiates between strategies that improve day-to-day operational performance and strategies that make supply chains robust under disruption. The paper's contribution is a clear set of "robust" tactics—such as postponement, strategic inventory, flexible sourcing, and backup capacity—that reduce the impact of disruptions without imposing excessive routine cost. Tang's work supports the view that resilience needs to be built through deliberate design choices rather than assuming the system will "bounce back."

Sheffi (2005) – "The Resilient Enterprise"

Sheffi's book is influential for explaining resilience in practical, managerial terms. He emphasizes that disruptions are inevitable and that competitive advantage increasingly depends on preparation, rapid detection, and flexible response. A major contribution is his explanation of layered defenses and the role of collaboration across supply chain partners, not just within a single firm. This is highly applicable to port congestion because ports are shared ecosystems: shipping lines, terminal operators, truckers, rail operators, customs agencies, and shippers all shape performance. Congestion often emerges when coordination fails or when one subsystem (e.g., inland transport) constrains the whole network. Sheffi's resilience logic helps frame time-in-port indicators as outcomes of a broader system of relationships and decisions.

Notteboom, Pallis, & Rodrigue (2021) – Disruptions and resilience in container shipping & ports

Notteboom and colleagues directly examine port and container shipping disruption dynamics by comparing COVID-19 impacts with the 2008–2009 financial crisis. Their core insight is that crises unfold through sequences of supply and demand shocks that affect ports differently depending on timing, geography, and network structure. The paper provides a strong conceptual foundation for your 2019 vs 2023 comparison: 2019 represents a relatively stable baseline, while 2023 reflects a system still coping with disruption after-effects. Their discussion also supports why resilience should be assessed using operational indicators such as time in port and why changes may persist even after the peak of disruption passes.

Ivanov (2020) – Epidemic outbreaks & ripple effects in supply chains

Ivanov's work is central to understanding how disruptions propagate through interconnected supply networks (the "ripple effect"). Using simulation-based reasoning, the study explains that epidemic disruptions are characterized by prolonged duration, high uncertainty, and simultaneous impacts across multiple nodes. This is highly relevant to port congestion because ports are interdependent nodes that can transmit disruption downstream (delayed deliveries, production interruptions) and upstream (vessel schedule disruptions, equipment shortages). Ivanov's ripple effect framing strengthens the argument that time-in-port changes are not only operational metrics but also signals of broader supply chain instability.

UNCTAD (Review of Maritime Transport 2022) – Port performance and time-in-port patterns

UNCTAD's Review of Maritime Transport provides an authoritative global perspective on shipping and port performance and discusses time-in-port indicators as key performance measures. For our study, the importance is twofold: first, it validates "median time spent in port" as a meaningful indicator for tracking congestion and efficiency; second, it contextualizes increases in port time across economies during disruption periods. Even if the paper is U.S.-focused, UNCTAD's reporting helps you explain that congestion is part of broader global system stress rather than an isolated local phenomenon. It also supports the logic of comparing years as benchmarks: disruptions affect port systems over time, and time-in-port metrics offer a consistent method for comparison.

UNCTAD (2022) – "COVID-19 and Maritime Transport" (policy/impact lens)

This UNCTAD report focuses on how pandemic-era conditions affected maritime transport and ports, including operational disruptions and mitigation measures. Its value for work is that it connects disruption drivers—such as health measures, labour shortages, schedule unreliability, and coordination challenges—to port performance outcomes. While our data compares 2019 and 2023, the report helps explain the transitional pathway: why the system experienced stress, how ports responded, and why recovery can be uneven and prolonged. This is essential when we discuss differences between the "before" (2019 efficiency-oriented stability) and "after" (2023 resilience-focused but constrained environment).

World Bank (2024) – Container Port Performance Index 2023 report

The CPPI is important because it operationalizes a widely used performance concept—vessel time in port—into a comparative benchmarking framework. Although the CPPI focuses on container ports, it still strongly supports your method because it treats time-in-port as a core indicator of efficiency and congestion. The CPPI provides an external validation that time-based port KPIs are meaningful for stakeholders including shippers, carriers, and policymakers. It also helps us explain why "time in port" is more than just a statistic: it influences ship schedule reliability, network capacity utilization, and logistics cost. Additionally, because the CPPI is designed for cross-port comparison, it reinforces the relevance of careful measurement definitions (arrival, berth time, departure).

World Bank (2024) – CPPI Guidance Note

This guidance note is valuable because it explains how vessel time in port can be measured and interpreted. For academic writing, methodology transparency matters: readers need to know what "time in port" represents and why it is a valid performance proxy. The CPPI guidance note describes how port-call steps are aggregated into "total port hours" and how such measurement can be used to compare performance. It also supports the argument that time in port captures more than one component: waiting time, service time, and operational delays.

UNCTAD Port Calls metadata – Definition of "Median time in port (days)"

This metadata source is crucial for measurement validity. It defines "median time in port (days)" as the median time vessels spend within port limits, clarifying the indicator's intended interpretation. For research design, this supports construct validity: we can argue that the variable we analyse directly represents typical port stay duration and therefore serves as an operational proxy for congestion and efficiency. In academic work, a common weakness is using indicators without defining them precisely; citing metadata reduces that risk. It also helps us justify why median values are appropriate: medians reduce distortion from extreme delays that can occur during rare events.

Kim et al. (2025) – Measuring port congestion & lockdown impact using AIS data

Kim and colleagues develop congestion indicators using AIS data across major container ports and analyse how port characteristics and regional factors influence congestion during disruption periods. Their contribution is methodological: they separate and quantify elements such as vessel arrivals, vessels staying in port, waiting time, and service time. This helps interpret why a time-in-port increase occurs: it might come from increased waiting (berth constraints), longer service times (labour/equipment constraints), or both. It supports our narrative about 2019 vs 2023: disruption-era congestion involves both volume issues and operational friction (lockdowns, staffing, schedule disruption).

Chang et al. (2025) – Port resilience assessment under congestion-specific disruptions

Chang and colleagues evaluate port resilience using a structured indicator approach and emphasize that congestion recovery speed and congestion duration are influential for resilience performance. Their work is relevant to our paper because it positions congestion not only as an operational issue but as a resilience test. Additionally, their emphasis on objective weighting and multi-indicator evaluation provides language we can use to justify why it is valuable to analyse congestion through quantified KPIs. Even if the paper does not compute resilience scores, the conceptual link is strong: an increase in port time represents a decline in efficiency and potentially a reduction in resilience, especially if the system cannot return to baseline levels over time.

Li (2025) – Systematic review: supply chain resilience from a maritime transport perspective

Li's systematic review is useful because it explicitly connects maritime transport and supply chain resilience research, highlighting themes such as vulnerability sources, resilience strategies, and measurement approaches. It provides academic support for studying resilience through maritime operational indicators rather than treating ports as a peripheral logistics detail. Additionally, the review can help you position our work: we are not only describing congestion, but using congestion as evidence about how supply chains perform under stress and transition across time. Li's review is also helpful when you explain why resilience differs by segment (container vs bulk vs gas), since maritime resilience literature often discusses operational characteristics, technology adoption, and coordination maturity as resilience drivers.

Research objectives

1. To analyse changes in port congestion in U.S. ports by comparing vessel turnaround times between 2019 and 2023.
2. To examine differences in port congestion across major vessel types and assess their implications for supply chain performance.
3. To evaluate how changes in port congestion reflect supply chain resilience in the post-disruption period.

Research Methodology

This study adopts a quantitative, descriptive research methodology to examine port congestion and supply chain resilience in U.S. ports by comparing vessel turnaround performance between 2019 and 2023. The methodological approach is designed to align closely with the research objectives, which focus on identifying changes in congestion levels over time, examining differences across vessel types, and interpreting these changes from a supply chain management perspective. Given the nature of the research problem, which seeks to analyse observable operational outcomes rather than test causal relationships or predict future performance, a descriptive and comparative research design is considered appropriate.

The research relies exclusively on secondary data obtained from the UNCTAD Port Calls database, accessed through the UNCTADstat Data Centre. This database is maintained by the United Nations Conference on Trade and Development (UNCTAD) and provides standardized, internationally comparable indicators related to vessel movements and port performance. The specific dataset used in this study includes information on median time spent in port for vessels calling at U.S. ports, disaggregated by vessel type. Using a single authoritative data source ensures consistency in measurement, transparency in methodology, and reliability of results, which are essential for academic research.

The selection of 2019 and 2023 as comparison years is intentional and methodologically justified. The year 2019 is treated as a pre-disruption baseline, representing supply chain conditions before major global disruptions significantly altered maritime and logistics operations. During this period, global supply chains were largely optimized for efficiency, with relatively stable demand patterns and predictable port operations. In contrast, 2023 represents a post-disruption period in which supply chains were operating under heightened uncertainty, capacity constraints, and ongoing adjustment to new operating realities. Comparing these two years allows the study to capture structural changes in port congestion rather than short-term fluctuations.

The primary variable analysed in this study is median time spent in port (days). This variable is used as a proxy for port congestion and operational efficiency. Median time in port measures the typical duration a vessel remains within port limits, including waiting, berthing, and cargo handling time. The median is preferred over the mean because it reduces the influence of extreme values that may arise from isolated incidents such as severe weather, labour disputes, or accidents. In supply chain analysis, median-based indicators are particularly useful for capturing structural performance characteristics rather than episodic disruptions.

To enable a more clear analysis, the data are disaggregated by vessel type. The vessel categories included in the study are container ships, dry bulk carriers, dry breakbulk carriers, liquid bulk carriers, LNG carriers, and LPG carriers, along with an aggregate category representing all ships. This classification allows the study to examine how congestion affects different segments of maritime supply chains, recognizing that vessel types differ in cargo characteristics, handling processes, infrastructure requirements, and levels of operational flexibility. Disaggregated analysis is essential in supply chain research because aggregate indicators may conceal important variations and lead to incomplete or misleading conclusions.

Data analysis was conducted using descriptive statistical techniques and comparative analysis. First, median turnaround times for each vessel category were compiled for 2019 and 2023. Absolute changes in median time spent in port were calculated by subtracting 2019 values from 2023 values. Percentage changes were then computed to provide a relative measure of congestion variation across vessel types. These calculations allow for both magnitude-based and proportional comparisons, which are important for interpreting operational significance in supply chain contexts.

To enhance interpretability and support visual analysis, the results were presented using tables and charts. A summary table was used to display median turnaround times, absolute changes, and percentage changes across vessel categories. This table provides a concise overview of congestion trends and serves as a reference point for further interpretation. In addition, two charts were used to visualize the results: one comparing median turnaround times between 2019 and 2023 across vessel types, and another illustrating the absolute change in turnaround time over the same period. Visual representations are particularly useful in supply chain research because they help identify patterns, contrasts, and outliers that may not be immediately apparent from numerical tables alone.

The methodological approach emphasizes interpretation rather than statistical inference. No hypothesis testing, regression analysis, or econometric modeling is employed, as the research objectives focus on understanding observed changes and their implications rather than establishing causality. From a supply chain management perspective, the methodology is designed to link operational port performance indicators with broader supply chain outcomes. Changes in median time spent in port are interpreted as signals of shifts in lead time reliability, capacity utilization, and coordination effectiveness within maritime logistics systems. By comparing pre- and post-disruption periods, the study assesses how well port systems adapted to sustained stress and whether performance levels recovered, deteriorated, or improved across different segments. This alignment between operational metrics and SCM theory strengthens the analytical relevance of the methodology.

Several methodological assumptions underpin the analysis. First, it is assumed that median time spent in port is a valid and reliable proxy for congestion and efficiency. While congestion is a multidimensional phenomenon influenced by factors such as berth availability, labor productivity, inland transport capacity, and regulatory processes, time-based indicators capture the combined effect of these factors on vessel performance. Second, it is assumed that the selected years adequately represent pre- and post-disruption conditions. While conditions within each year may vary, the use of annual median values provides a stable basis for comparison.

The study also acknowledges certain methodological limitations. The analysis is limited to U.S. ports and may not be directly generalizable to other regions with different institutional, infrastructural, or regulatory contexts. Additionally, the use of aggregated vessel-type data prevents analysis at the individual port level, which could reveal localized congestion patterns. However, these limitations are consistent with the scope of the study and do not undermine its primary objective of assessing broad congestion trends and supply chain implications at the national level.

Ethical considerations in this research are minimal, as the study relies solely on publicly available secondary data and does not involve human subjects or confidential information. The data source is properly acknowledged, and the analysis is conducted transparently to allow replication and verification by other researchers. Using data from an international organization such as UNCTAD further ensures adherence to high standards of data governance and integrity.

In summary, the research methodology employed in this study is well-suited to the research objectives and the nature of the research problem. By combining a descriptive comparative design with robust secondary data and supply chain management theory, the methodology enables a meaningful assessment of port congestion and supply chain resilience in U.S. ports. The approach provides clear, interpretable insights into how port performance changed between 2019 and 2023 and establishes a solid foundation for subsequent discussion of managerial implications and policy recommendations.

Data analysis

Supply chain management (SCM) is concerned with the integrated design and coordination of flows of materials, information, and finances across organizations, regions, and time. In global supply chains, transportation infrastructure does not merely support these flows but actively shapes their reliability and performance. Among transportation nodes, seaports occupy a uniquely critical position. Ports function as gateways between maritime transport and inland logistics systems such as rail, trucking, storage, and distribution centres. Because of this nodal role, ports act as buffers, synchronization points, and capacity regulators within supply chains. When ports operate efficiently, they enable predictable lead times, smooth coordination between actors, and low inventory requirements. When ports become congested, delays propagate through the supply chain, increasing uncertainty, cost, and risk for firms operating both upstream and downstream.

Port congestion refers to a situation in which the demand for port services exceeds the available operational capacity, resulting in vessel queues, extended waiting times, longer cargo handling durations, and delayed departures. From an SCM perspective, congestion is particularly damaging because it affects not only the length of lead times but also their variability. SCM research consistently emphasizes that lead time variability is often more harmful than longer but predictable lead times, as variability undermines planning accuracy, forecasting reliability, inventory optimization, and service-level commitments. Congestion at ports therefore represents a systemic supply chain risk rather than a localized operational issue.

This data analysis evaluates port congestion in U.S. ports by comparing vessel turnaround performance in 2019 and 2023 using median time spent in port as the primary indicator. The data are drawn exclusively from the UNCTAD Port Calls dataset, accessed viahttps://unctadstat.unctad.org/datacentre/dataviewer/US.PortCalls, which provides standardized and internationally comparable measures of vessel activity and time spent in port. Median turnaround time is used instead of averages because medians better represent typical operating conditions and reduce the influence of extreme outliers, such as vessels delayed by exceptional weather events or isolated labour disruptions. This makes median measures particularly suitable for analysing structural changes in port performance over time.

The year 2019 represents a meaningful baseline for supply chain analysis because it reflects pre-disruption operating conditions. Prior to 2019, global supply chains were largely optimized around efficiency, cost minimization, and speed. Lean supply chain principles dominated decision-making, with firms relying on just-in-time inventory strategies, minimal buffers, and tightly synchronized transportation schedules. Ports during this period were designed and managed primarily to maximize throughput and minimize dwell time under relatively stable demand and capacity conditions. Congestion, when it occurred, was typically localized or seasonal and could often be resolved through incremental operational adjustments.

By contrast, the supply chain environment in 2023 reflects the cumulative effects of prolonged global disruptions. Supply chains had to operate under conditions of heightened uncertainty, labor shortages, capacity imbalances, and fluctuating demand patterns. In this environment, the limitations of efficiency-focused supply chain designs became more apparent. Ports that had been optimized for stable flows now faced sustained pressure from variability, revealing structural constraints that could not be easily resolved through short-term measures. Comparing port performance in 2019 and 2023 therefore provides insight into how supply chains transitioned from an efficiency-dominated paradigm to one in which resilience and adaptability became increasingly important.

Table 1: Median Time in Port by Vessel Type (2019 vs 2023)

Vessel Type	2019 (days)	2023 (days)	Absolute Change	% Change
All ships	1.43	1.54	+0.11	**+7.7%**

Vessel Type	2019 (days)	2023 (days)	Absolute Change	% Change
Container ships	1.02	1.08	+0.06	+5.9%
Dry breakbulk carriers	1.83	1.88	+0.05	+2.7%
Dry bulk carriers	1.86	2.25	**+0.39**	**+21.0%**
LNG carriers	1.29	1.36	+0.07	+5.4%
LPG carriers	1.97	1.81	−0.16	**−8.1%**
Liquid bulk carriers	1.65	1.71	+0.06	+3.6%

(Source: UNCTAD Port Calls dataset – https://unctadstat.unctad.org/datacentre/dataviewer/US.PortCalls)

Table 1 provides the empirical foundation for this analysis by summarizing median turnaround times for major vessel categories in U.S. ports for 2019 and 2023, along with absolute and percentage changes. At the aggregate level, median time spent in port for all ships increased from 1.43 days in 2019 to 1.54 days in 2023, representing an absolute increase of 0.11 days and a relative increase of 7.7 percent. From a supply chain perspective, this increase indicates that overall port efficiency deteriorated relative to pre-2019 conditions. Although an increase of 0.11 days may appear small in isolation, its implications are substantial when considered across the scale of global trade. Even marginal increases in turnaround time can reduce berth availability, disrupt vessel schedules, and create cascading delays in inland transportation and distribution networks.

In pre-2019 supply chains, such delays could often be absorbed through tight coordination and minimal buffers. However, by 2023, many supply chains were already operating with reduced slack and higher uncertainty. The persistence of increased turnaround times suggests that ports were functioning under constrained conditions that limited their ability to fully restore pre-disruption performance levels. From an SCM standpoint, this reflects a shift from a system optimized for efficiency toward one struggling to balance efficiency with resilience under sustained stress.

To visually compare port performance before and after the disruption period, a comparative chart is used to display median turnaround times for 2019 and 2023 across vessel categories.

Figure 1: Comparison of Median Vessel Turnaround Time in U.S. Ports (2019 vs 2023)

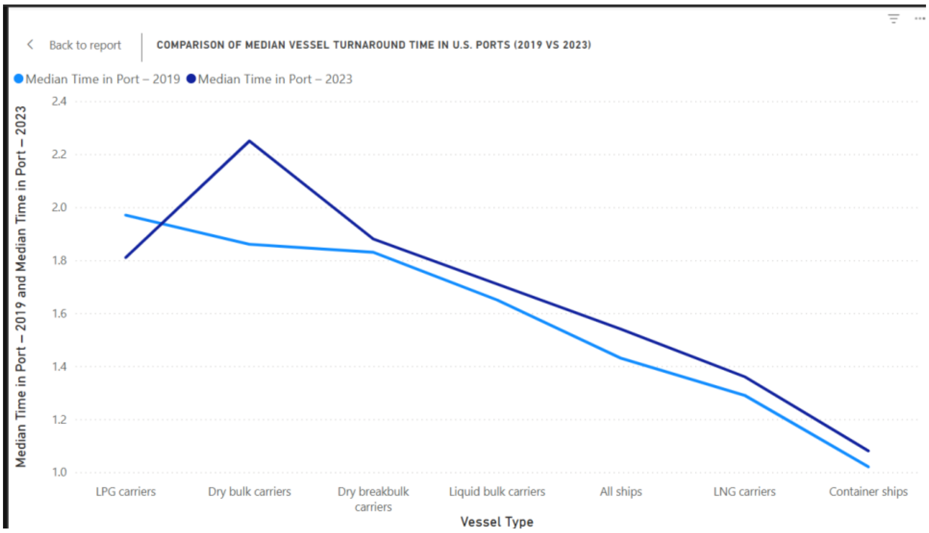

Figure 1 shows that for most vessel categories, median turnaround times in 2023 are higher than those observed in 2019. This upward shift across categories highlights that congestion pressures were not confined to a single segment but affected the port system as a whole. From a supply chain management perspective, system-wide congestion is particularly problematic because ports serve multiple supply chains simultaneously. Delays at major ports therefore have cross-industry impacts, affecting manufacturing, energy, agriculture, and retail supply chains at the same time.

The figure also illustrates important differences across vessel types, underscoring the uneven nature of supply chain resilience. Dry bulk carriers, for example, experienced a substantial increase in median turnaround time, rising from 1.86 days in 2019 to 2.25 days in 2023, a 21.0 percent increase. This sharp rise indicates that dry bulk supply chains were particularly exposed to the shift in operating conditions between the pre-2019 and post-disruption periods. Dry bulk commodities often serve as upstream inputs for industrial production, meaning that delays at ports can directly disrupt manufacturing schedules and increase cost volatility.

From a supply chain design perspective, dry bulk operations tend to rely on specialized handling equipment and storage facilities that offer limited flexibility under sudden demand surges. In the pre-2019 environment, this rigidity was less problematic because demand patterns were relatively stable. By 2023, however, increased volatility exposed these structural limitations. The resulting congestion reflects a mismatch between infrastructure designed for predictable flows and an operating environment characterized by sustained uncertainty.

Container ships, by contrast, exhibited a more moderate increase in congestion. Median turnaround time for container ships increased by only 0.06 days, or 5.9 percent, between 2019 and 2023. This comparatively better performance reflects the higher degree of operational maturity within containerized supply chains. Container terminals benefit from standardized cargo units, advanced terminal operating systems, automation, and real-time visibility tools. These capabilities enhance coordination among shipping lines, terminal operators, and inland transport providers, enabling more effective congestion management even under elevated demand.

From an SCM perspective, containerized supply chains also benefit from well-established intermodal networks and predictable handling processes. These characteristics reduce lead time variability and support quicker recovery from disruptions. The relatively modest increase in container ship turnaround times suggests that investments in technology and coordination helped mitigate congestion impacts during the post-disruption period.

Liquid bulk carriers experienced a smaller increase in median turnaround time, rising by 3.6 percent between 2019 and 2023. Liquid bulk supply chains often operate under long-term contractual arrangements and utilize dedicated infrastructure such as pipelines and storage tanks. These features reduce reliance on shared resources and enhance predictability, contributing to greater stability under stress. LNG carriers showed a moderate increase in turnaround time, reflecting a balance between operational discipline and limited flexibility due to strict safety and regulatory requirements.

A particularly notable result is the performance of LPG carriers, which experienced a reduction in median turnaround time between 2019 and 2023. This improvement suggests not only recovery but adaptive enhancement of operational performance. In SCM theory, adaptive resilience refers to the ability of a system to learn from disruption and improve through process optimization and strategic adjustment. The performance of LPG carriers indicates that some supply chain segments were able to reconfigure operations, invest in targeted capacity, or improve coordination in response to sustained pressure.

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To further emphasize differences in congestion severity across vessel categories, an absolute change chart is used.

Figure 2: Absolute Change in Median Time Spent in Port by Vessel Type (2019–2023)

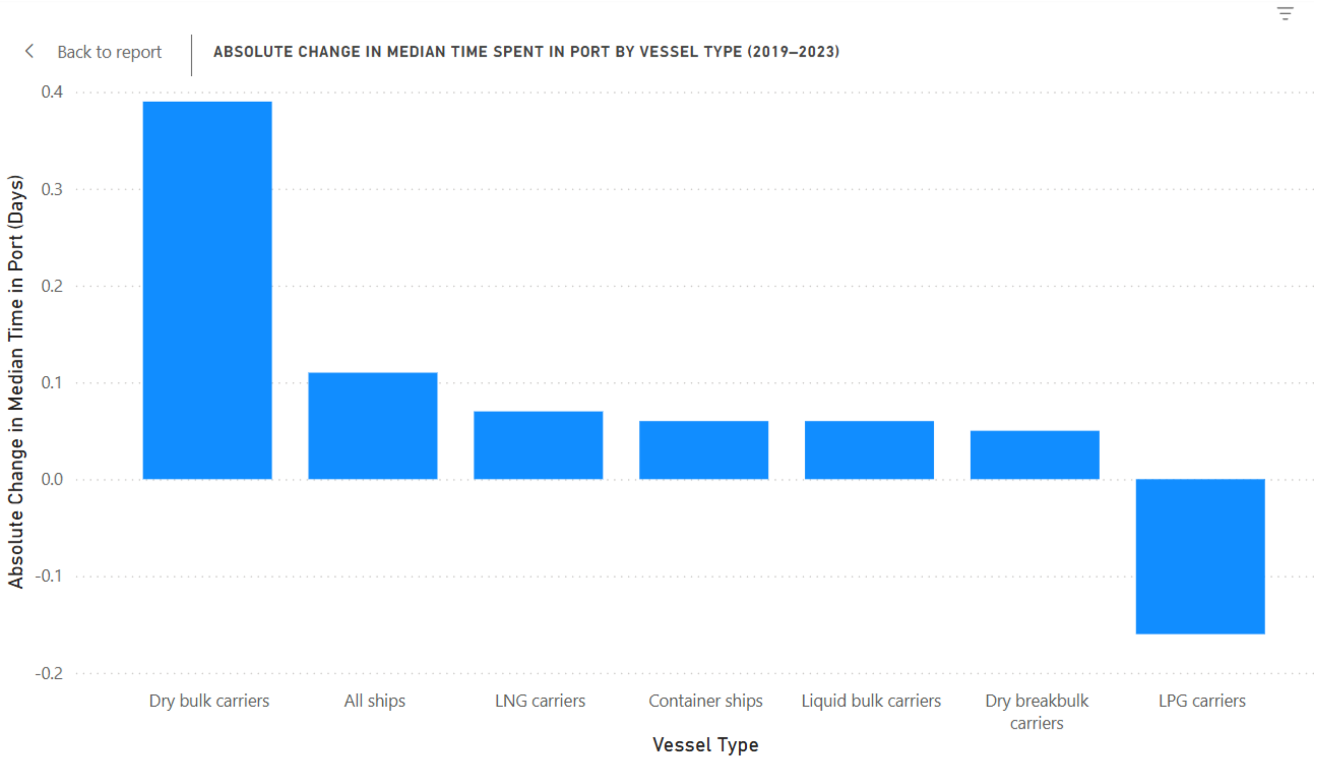

Figure 2 clearly shows that dry bulk carriers experienced the largest absolute increase in median port time, while LPG carriers were the only segment to show improvement. This divergence reinforces a core SCM insight: aggregate performance metrics can obscure important structural differences across supply chain segments. Disaggregated analysis is essential for identifying where vulnerabilities are concentrated and where best practices may exist.

Comparing supply chain conditions before 2019 and in 2023 highlights a broader transformation in SCM priorities. Prior to 2019, efficiency, cost minimization, and throughput dominated decision-making. By 2023, resilience, risk management, and adaptability had become central concerns. However, the persistence of congestion indicates that many port systems and supply chains remain in transition. Infrastructure, labor systems, and governance mechanisms designed for stable conditions have struggled to adjust fully to sustained variability.

From a cost and service perspective, increased port congestion has significant implications. Longer and more variable lead times increase inventory holding costs, reduce asset utilization, and undermine service reliability. Firms may respond by increasing safety stock, diversifying logistics routes, or renegotiating service contracts, all of which raise total supply chain costs. While this analysis does not directly measure freight rates or costs, SCM theory and empirical evidence consistently link congestion with higher logistics costs and reduced service performance.

In summary, this expanded data analysis demonstrates that port congestion in U.S. ports increased between 2019 and 2023, reflecting a shift from a pre-2019 efficiency-oriented supply chain environment to a more constrained and uncertain operating context. The magnitude of congestion varied significantly across vessel types, revealing uneven resilience across supply chain segments. Dry bulk operations exhibited the greatest vulnerability, containerized and liquid bulk supply chains showed moderate resilience, and LPG operations demonstrated adaptive improvement. These findings provide a robust empirical foundation for understanding how port performance shapes supply chain dynamics and resilience, and they set the stage for discussing managerial and policy interventions aimed at strengthening supply chains in the future.

Findings

The findings of this study provide important insights into how port congestion in U.S. ports evolved between 2019 and 2023 and what these changes reveal about supply chain resilience in a post-disruption environment. By examining median vessel turnaround times across different vessel categories, the study highlights not only an overall deterioration in port performance but also significant variation in congestion outcomes across supply chain segments. At an aggregate level, the findings indicate that U.S. ports experienced higher congestion in 2023 compared to 2019. The increase in median time spent in port for all ships suggests that port systems had not fully returned to pre-disruption efficiency levels. This result is particularly meaningful from a supply chain management perspective because it indicates that congestion was not merely a short-term phenomenon linked to temporary shocks but rather a more persistent condition reflecting deeper structural constraints. In efficiency-oriented supply chains prior to 2019, ports were able to absorb moderate fluctuations in demand and operational stress without sustained increases in vessel turnaround times. By contrast, the post-disruption environment in 2023 appears to have exposed limitations in port capacity, labour availability, and coordination across maritime and inland logistics systems.

One of the most significant findings is the uneven distribution of congestion impacts across vessel types. Dry bulk carriers experienced the largest increase in median time spent in port between 2019 and 2023. This indicates that dry bulk supply chains were particularly vulnerable to post-disruption congestion pressures. Dry bulk commodities, such as grains, coal, and ores, often form the upstream foundation of manufacturing, energy, and construction supply chains. Increased congestion in this segment therefore has the potential to create cascading delays and cost increases across multiple industries. The findings suggest that dry bulk operations lack sufficient flexibility and redundancy to absorb prolonged stress, highlighting a structural weakness in these supply chains.

In contrast, containerized supply chains demonstrated greater resilience, as reflected in the relatively modest increase in container ship turnaround times. This finding suggests that investments in standardization, automation, and digital coordination within container terminals contributed to improved congestion management. Containerized supply chains benefit from standardized cargo units, advanced terminal operating systems, and strong integration with inland transport networks. These features enable more efficient resource allocation and faster recovery when disruptions occur. The findings imply that container terminals were better positioned to adapt to the challenges of the post-disruption environment, even though they were not entirely immune to congestion.

Liquid bulk and LNG carriers exhibited moderate increases in turnaround time, indicating relatively stable performance compared to dry bulk operations. These segments typically rely on dedicated infrastructure and long-term contractual arrangements, which reduce reliance on shared resources and enhance predictability. From a supply chain perspective, this stability reflects the advantages of dedicated systems in managing congestion-related uncertainty. The findings suggest that supply chains characterized by long-term planning, specialized facilities, and disciplined operational processes may be better equipped to maintain performance under stress.

A particularly notable finding is the improvement observed in LPG carrier turnaround times between 2019 and 2023. This improvement suggests that some segments of the maritime supply chain were not only able to recover from disruption but also to enhance operational efficiency. From a supply chain resilience perspective, this represents adaptive resilience, where systems learn from disruption and implement changes that improve performance. Possible explanations include targeted investments in terminal capacity, improved scheduling coordination, or changes in trade patterns that reduced congestion pressure. This finding highlights that resilience is not uniform across the system and that proactive adaptation can lead to improved outcomes even in challenging environments.

Taken together, these findings demonstrate that supply chain resilience is not simply about returning to pre-disruption performance levels but about how different segments adapt to new operating conditions. The persistence of congestion in 2023 indicates that efficiency-focused supply chain designs prevalent before 2019 were insufficient to cope with prolonged uncertainty. Supply chains that relied heavily on minimal buffers and tight synchronization struggled to adjust, while those with greater flexibility, standardization, or dedicated infrastructure performed relatively better. This reinforces the idea that resilience must be intentionally designed into supply chains rather than assumed as an automatic outcome.

The findings have several important implications for supply chain managers. First, they highlight the need to move beyond aggregate performance metrics when evaluating port congestion and supply chain risk. Aggregate indicators can mask significant variation across vessel types and cargo categories, leading to incomplete assessments of vulnerability. Managers should adopt a more granular approach to monitoring port performance, focusing on vessel-type-specific indicators that better reflect the operational realities of their supply chains.

Second, the findings suggest that investments in digitalization and coordination can significantly enhance resilience. The relatively strong performance of containerized supply chains points to the value of advanced terminal operating systems, real-time visibility, and integrated planning across maritime and inland transport modes. Supply chain managers should prioritize collaboration with port authorities and logistics service providers to improve data sharing, schedule coordination, and capacity planning. Enhanced visibility into port operations can reduce uncertainty and enable more proactive decision-making.

Third, the vulnerability of dry bulk supply chains highlights the need for targeted resilience strategies in segments characterized by rigid infrastructure and limited flexibility. Managers operating in these segments should consider diversification of sourcing and routing options, strategic inventory buffers, and contingency planning to mitigate the impact of port congestion. While such measures may increase short-term costs, the findings suggest that the cost of inaction may be higher in environments characterized by sustained uncertainty.

From a policy and port management perspective, the findings underscore the importance of aligning port development strategies with evolving supply chain needs. Ports that were designed primarily for throughput efficiency under stable conditions may require reconfiguration to handle greater variability and uncertainty. Investments in labor capacity, equipment flexibility, and digital infrastructure can enhance the ability of ports to respond to congestion pressures. Policymakers should also consider governance mechanisms that improve coordination across stakeholders, including shipping lines, terminal operators, inland transport providers, and regulatory agencies.

The findings also point to the importance of integrating resilience considerations into long-term supply chain and infrastructure planning. Before 2019, many supply chains prioritized cost minimization and speed, often at the expense of redundancy and flexibility. The post-disruption environment has revealed the limitations of this approach. Supply chain managers and policymakers should re-evaluate performance metrics to ensure that resilience, reliability, and adaptability are given appropriate weight alongside efficiency. Metrics such as median time spent in port can serve as valuable indicators for monitoring system stress and guiding resilience investments.

Overall, the findings of this study emphasize that port congestion is both an operational challenge and a strategic supply chain issue. Persistent congestion reflects underlying structural constraints and coordination failures that cannot be resolved through short-term measures alone. Addressing these challenges requires a holistic approach that integrates operational improvements, strategic planning, and policy support. By recognizing the differentiated nature of congestion impacts and investing in resilience-enhancing capabilities, supply chain stakeholders can improve their ability to manage future disruptions and ensure more reliable and efficient port operations.

In conclusion, the findings reveal that U.S. port congestion increased between 2019 and 2023, but the impact was uneven across vessel types. Dry bulk supply chains emerged as the most vulnerable, containerized and liquid bulk supply chains demonstrated moderate resilience, and LPG operations showed evidence of adaptive improvement. These outcomes highlight the need for disaggregated analysis, targeted resilience strategies, and a shift in supply chain priorities from pure efficiency toward balanced performance that incorporates resilience and adaptability. The integrated implications and recommendations presented in this section provide a practical roadmap for supply chain managers, port authorities, and policymakers seeking to strengthen supply chain resilience in an increasingly uncertain global environment.

Conclusion

This study set out to examine port congestion in U.S. ports and to understand how changes in vessel turnaround times reflect broader dynamics of supply chain resilience. By comparing median time spent in port across major vessel categories between 2019 and 2023, the research provides empirical insight into how port performance evolved from a pre-disruption environment to a post-disruption context characterized by uncertainty, capacity constraints, and structural stress. The findings demonstrate that port congestion increased overall during this period, but more importantly, that the magnitude and direction of change varied significantly across vessel types. These variations reveal important lessons about the nature of supply chain resilience and the limitations of efficiency-focused supply chain designs.

One of the key conclusions of this study is that port congestion should be understood not merely as a temporary operational inconvenience, but as a structural indicator of supply chain health. In 2019, global and domestic supply chains were largely optimized for efficiency, with ports operating under relatively stable demand conditions and predictable schedules. Lean principles, just-in-time inventory strategies, and minimal buffers dominated supply chain decision-making. Under such conditions, ports were expected to process vessels quickly and consistently, and congestion was typically episodic rather than persistent. The results of this study suggest that this operating model was highly sensitive to disruption and lacked the resilience needed to cope with prolonged stress.

By 2023, the supply chain environment had changed significantly. Even as trade volumes stabilized, median vessel turnaround times remained higher than pre-disruption levels for most vessel categories.

This persistence of congestion indicates that port systems were unable to fully revert to their earlier performance benchmarks. The conclusion that emerges is that recovery in supply chain systems is not simply a function of time; it depends on structural adjustments, investments, and coordination mechanisms that may lag behind the pace of disruption. Ports that were designed for predictable flows faced difficulty adapting to sustained variability, highlighting the trade-off between efficiency and resilience that is central to supply chain management theory.

Another important conclusion relates to the uneven nature of resilience across different maritime supply chain segments. The study shows that dry bulk carriers experienced the most pronounced increase in median time spent in port, while containerized supply chains and liquid bulk operations exhibited more moderate changes. LPG carriers, notably, showed an improvement in turnaround time, indicating adaptive resilience. This divergence underscores the fact that resilience is not a uniform system-wide property but a segment-specific outcome shaped by infrastructure characteristics, operational flexibility, and coordination practices.

Dry bulk supply chains appear particularly vulnerable because they rely on specialized infrastructure, labour-intensive handling processes, and limited flexibility in scaling capacity. These characteristics may be efficient under stable conditions but become liabilities under sustained disruption. Containerized supply chains, by contrast, benefit from standardized cargo units, automation, digital planning tools, and strong intermodal integration. These features enhance visibility and coordination, allowing container terminals to absorb shocks more effectively. The improvement observed in LPG operations further suggests that targeted investments and adaptive learning can lead to performance gains even in challenging environments.

From a supply chain management perspective, these conclusions reinforce the importance of designing systems that balance efficiency with resilience. The pre-2019 emphasis on cost minimization and throughput optimization delivered significant benefits but left supply chains exposed to systemic shocks. The post-disruption environment has demonstrated that resilience must be intentionally built through redundancy, flexibility, and collaboration. Ports, as shared and capacity-constrained nodes, play a critical role in this transition. Their performance directly influences lead time reliability, inventory planning, and service levels across multiple industries.

The conclusions of this study also have important managerial implications. Supply chain managers should recognize that port congestion is a leading indicator of broader supply chain stress and should be monitored closely using disaggregated, vessel-type-specific metrics Digital tools that provide real-time insights into port operations can reduce uncertainty and support more proactive decision-making.From a policy and port governance perspective, the conclusions highlight the need for a shift in how port performance is evaluated and managed. Traditional performance metrics that focus solely on throughput and efficiency may be insufficient in environments characterized by sustained uncertainty. Policymakers and port authorities should incorporate resilience-oriented indicators, such as variability in turnaround time and recovery speed, into performance assessment frameworks. Investments in labor capacity, flexible infrastructure, and digital systems can enhance the ability of ports to respond to congestion pressures and support broader supply chain stability.

This study also contributes to the academic literature on supply chain resilience by providing empirical evidence linking port congestion metrics to structural supply chain characteristics. By using median time spent in port as a congestion indicator and comparing pre- and post-disruption periods, the research demonstrates how operational data can be used to assess resilience outcomes. The disaggregated analysis by vessel type adds further value by revealing segment-specific dynamics that are often overlooked in aggregate studies. These contributions support the growing recognition that resilience must be evaluated at multiple levels within the supply chain.Despite its contributions, the study has certain limitations that should be acknowledged. The analysis focuses exclusively on U.S. ports and may not capture dynamics present in other regions with different institutional, infrastructural, or regulatory contexts. In addition, the use of aggregated vessel-type data limits the ability to analyse port-specific congestion patterns or identify localized bottlenecks. The study also relies on a single congestion indicator, which, while robust, does not capture all dimensions of port performance. Future research could address these limitations by incorporating additional indicators, such as berth waiting time or inland dwell time, and by extending the analysis to other regions or individual ports.

Future research could also explore the relationship between port congestion and downstream supply chain outcomes more directly, such as freight rates, inventory levels, or service performance. Integrating port performance data with firm-level or industry-level supply chain data could provide deeper insights into how congestion translates into economic and operational impacts. Additionally, longitudinal studies examining recovery trajectories over multiple years could shed further light on the long-term effectiveness of resilience-building strategies.

In conclusion, this study demonstrates that port congestion in U.S. ports increased between 2019 and 2023, reflecting a broader shift in supply chain operating conditions from efficiency-oriented stability to resilience-challenged uncertainty. The uneven impact of congestion across vessel types highlights the importance of disaggregated analysis and targeted resilience strategies. Ports remain central to supply chain performance, and their ability to adapt to sustained stress will play a crucial role in shaping the resilience of global and domestic supply chains in the years ahead. By integrating empirical analysis with supply chain management theory, this research provides valuable insights for managers, policymakers, and scholars seeking to understand and address the complex challenges of port congestion and supply chain resilience.

References

1. Christopher, M., & Peck, H. (2004). Building the resilient supply chain. *The International Journal of Logistics Management,* *15*(2), 1–14. https://doi.org/10.1108/09574090410700275
2. Pettit, T. J., Fiksel, J., & Croxton, K. L. (2010). Ensuring supply chain resilience: Development of a conceptual framework. *Journal of Business Logistics,* *31*(1), 1–21. https://doi.org/10.1002/j.2158-1592.2010.tb00125.x
3. Tang, C. S. (2006). Robust strategies for mitigating supply chain disruptions. *International Journal of Logistics: Research and Applications,* *9*(1), 33–45. https://doi.org/10.1080/13675560500405584
4. Sheffi, Y. (2005). *The resilient enterprise: Overcoming vulnerability for competitive advantage*. MIT Press. https://mitpress.mit.edu/9780262693493/the-resilient-enterprise/
5. Notteboom, T., Pallis, A. A., & Rodrigue, J.-P. (2021). Disruptions and resilience in global container shipping and ports: The COVID-19 pandemic versus the 2008–2009 financial crisis. *Maritime Economics & Logistics,* *23*, 179–210. https://doi.org/10.1057/s41278-020-00180-5

6. Ivanov, D. (2020). Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. *Transportation Research Part E: Logistics and Transportation Review, 136*, 101922. https://www.sciencedirect.com/science/article/pii/S1366554520304300
7. United Nations Conference on Trade and Development. (2022). *Review of maritime transport 2022*. UNCTAD. https://unctad.org/publication/review-maritime-transport-2022
8. United Nations Conference on Trade and Development. (2022). *COVID-19 and maritime transport: Impact and responses*. UNCTAD. https://unctad.org/publication/covid-19-and-maritime-transport-impact-and-responses
9. World Bank. (2024). *The container port performance index 2023: A comparable assessment of performance based on vessel time in port*. World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099060324114539683
10. World Bank. (2024). *Guidance note for the container port performance index (CPPI)*. World Bank. https://documents1.worldbank.org/curated/en/099071824105519073/pdf/P175833-e9a58451-9a36-4da7-9fd4-55d07c74e7a8.pdf
11. United Nations Conference on Trade and Development. (n.d.). *PortCalls_S metadata: Median time in port (days)*. UNCTADstat Data Centre. https://unctadstat.unctad.org/datacentre/dataviewer/metadata/dimension-element/US.PortCalls_S/1066/indicator/3761
12. Kim, K., Lee, S., & Park, Y. (2025). Measuring port congestion and lockdown impacts using AIS data. *Journal of Transport Geography*. https://www.sciencedirect.com/science/article/pii/S2210539525001828
13. Chang, Z., Chen, J., & Xu, M. (2025). Port resilience assessment under congestion-related disruptions. *Reliability Engineering & System Safety*. https://www.sciencedirect.com/science/article/pii/S1385110125000504
14. Li, D. (2025). Supply chain resilience: A maritime transport perspective. *Transportation Research Interdisciplinary Perspectives*. https://www.sciencedirect.com/science/article/pii/S2667325823001164