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# International Port Dependencies and Resilience to Supply Chain Disruptions

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## Abstract

The COVID-19 pandemic caused unprecedented disruptions in global supply chains and port operations, leading to congestion, delays, and container shortages. Governments implemented containment measures, affecting social and economic activity. Ports faced similar significant challenges due to shifts in demand, labor shortages, and supply chain bottlenecks. E-commerce surge and disruptions like the Suez Canal blockage further intensified pressures on ports. The pandemic's impact, coupled with other events, exacerbated challenges for ports and supply chains, triggering inflationary pressures. This research sought to investigate the impact of COVID-19 and other events on port efficiency and the global supply chain at major ports such as the Port of Long Beach, Port of New York and New Jersey, Port of Rotterdam, and Port of Shanghai. The objectives of the research included quantifying shipping volume, identifying trends, analyzing factors, and enhancing understanding for policymakers and stakeholders in building resilient supply chains. The primary finding of the research is that congestion in U.S. ports may have been attributed to consumer spending and unprecedented container throughput which overwhelmed the ports. In contrast, the Port of Rotterdam and Port of Shanghai maintained vessel dwell times more consistent with pre-Covid, suggesting process efficiency and resilience. The research results also highlight the vulnerability of U.S. ports to changes in consumer spending, leading to an influx of goods and overloaded ports, reducing efficiency and increasing dwell times.

# 1. Introduction

The COVID-19 pandemic, which emerged in late 2019, caused unprecedented disruptions on global supply chains and port operations. The rapid spread and high fatality rate of COVID-19 also created widespread anxiety and uncertainty across the world, necessitating swift and coordinated actions to curb its transmission [1]. Governments across the world implemented containment measures, including lockdowns, social distancing, and travel restrictions, leading to major deviations in social behavior and economic activity [1]. The magnitude of the pandemic's impact was far-reaching, with the U.S. economy experiencing significant job losses and global economic growth plummeting [3, 4]. Among its other numerous impacts was significant congestion, delay, and shortages of shipping containers at ports around the world [1, 2].

Supply chain disruptions, further fueled by shifts in demand for goods, labor shortages, lockdowns, and supply chain bottlenecks, compounded the challenges faced by the maritime transportation systems [5]. Additionally, the surge in e-commerce, accelerated by changes in consumer preferences and monetary policies, intensified pressures on ports, leading to backlogs and shipping delays [6,7]. This, combined with a shortage of truck drivers and containers further contributed to port congestion, hindering the efficient flow of cargo [8, 9].

As the pandemic's effects impacted global trade and transportation networks, ports also experienced notable congestion and delays. For instance, the ports of Long Beach, Los Angeles, and Oakland in California experienced a record number of ships waiting to enter in 2021 [2]. Similarly, the Port of Shanghai, a key region for global shipping and trade, faced significant congestion, resulting in delays in shipments to the major consumer markets of the U.S. and Europe [10]. The pandemic's far-reaching impacts, later coupled with other disruptive events such as the Suez Canal blockage and weather disasters, further contributed to the challenges faced by ports and supply chains [11, 12]. Ultimately, the disruptions to supply chains triggered global inflationary pressures, with increased shipping and production costs leading to higher consumer prices [13].

A comprehensive understanding of the ramifications of COVID-19 and other world events on port efficiency and supply chain resilience is critical for industry and governmental policy-making. This paper discusses research to investigate aspects of COVID-19 and associated disruptive event impacts on port efficiency and the role of shipping on supply chains. More specifically the research used container shipping data (including ship arrivals, departures, and associated timestamps) and container throughput at four internationally-significant ports, including the Ports of:

- Long Beach California. the largest container port in the US;
- New York and New Jersey, the second largest container port in the US;
- Rotterdam Netherlands, the largest container port in Europe; and
- Shanghai China, the largest container port in the world [15].

The research included four objectives, to:

1. Quantify dwell times, and container throughput at the selected ports during the study period.

2. Identify and analyze trends in shipping operations at these ports over the course of the study.
3. Investigate the factors that may have contributed to the identified trends, with a particular focus on the impact of the COVID-19 pandemic on port congestion and efficiency.
4. Increase understanding of the challenges faced by ports during the COVID-19 pandemic and other world events.

## 2. Literature Review

Maritime transport is a critical link in the global supply chain, facilitating the majority of global merchandise trade by volume and value [16]. However, the COVID-19 pandemic has disrupted maritime transportation networks and global supply chains, leading to economic destabilization and impacting worldwide trade [1]. Extensive research has been conducted to understand the repercussions of the pandemic on the maritime industry and its implications for global trade.

The United Nations Conference on Trade and Development (UNCTAD) assessed the immediate impacts of the COVID-19 disruption on the maritime supply chain and global trade during the first half of 2020. They found an 8.7 percent decrease in global ship calls, with developed countries experiencing a more substantial decline of 23.1 percent compared to developing countries and economies in transition [17]. Ports implemented operational adjustments, financial measures, sanitary protocols, and digitalization strategies to ensure continuity of operations and mitigate personnel shortages [17].

Studies using maritime traffic data from Automatic Identification Systems (AIS) receivers quantitatively assessed the short-term effects of COVID-19 and containment measures on global shipping mobility. Researchers revealed an unprecedented drop in maritime mobility during the strictest restriction period from March to June 2020 [16]. Specific studies explored the impact on shipping trade between major economies, observing that virus prevention efforts and national macroeconomic situations were linked to the shipping industry [18]. Other research focused on dry bulk and container transportation, indicating a significant decline in global dry bulk transportation and reduced container throughput at major ports [19].

Studies on ports' immediate impact highlighted their adaptation to the pandemic, minimizing disruptions to maritime transport and supply chains [20]. Changes in the maritime network due to COVID-19 resulted in decreased global maritime connectivity, with varying impacts on port hierarchies across regions [21]. Liner schedule cancellations indicated the pandemic's impact on global supply chains, particularly in the context of liner shipping network disruptions [22].

Assessing the effects of COVID-19 control measures on the global supply chain through a modeling framework demonstrated that the number of countries imposing restrictions and the duration of lockdowns significantly influenced supply chain losses [23]. Port production, efficiency, and resiliency were examined, revealing significant impacts on GDP and sectors like passenger transportation [24], while some ports displayed resilience through technology and efficiency-driven productivity during the pandemic [25].

Port congestion increased during the pandemic, contributing to supply chain issues. Models were developed to identify and prioritize port congestion risks, providing insights into risk prevention and mitigation strategies [26]. A conceptual framework was proposed to manage disruptions effectively by building flexibility into interrelated port logistics capacity elements [27].

Disruptions at ports during the pandemic led to shipping delays. Studies identified substantial delays at certain ports, particularly in the US and China, where shipping times increased dramatically [28]. Labor disputes further affected port performance, leading to declines in container volumes and ship calls [29]. Research on the impact of natural disasters on ports highlighted the median disruption duration and emphasized the importance of big data analytics in understanding supply chain disruptions [30, 31]. Port congestion increased after the pandemic, leading to higher levels of congestion [32]. Ports with high exposure to climate extremes were identified, indicating vulnerability to coastal flood exposures [33]. The cost consequences of port-related threats on supply chains emphasized the significance of disruption management and collaboration between ports and stakeholders [34].

Supply chain disruptions during the COVID-19 pandemic had significant implications for inflation and economic activity. Global supply chain bottlenecks and foreign shocks played a significant role in explaining euro area inflation [35]. Exposure to foreign bottlenecks through global value chains also impacted U.S. producer price index inflation [36].

The shortage of shipping containers during the pandemic severely affected the North American supply chain. Increased spending on durable goods during the pandemic was attributed to altered consumer tastes and increased disposable income [6]. Heightened demand for imported goods resulted in a massive backlog and price increase in the shipping container market, straining agricultural exporters and affecting dock workers [37]. Alternative solutions were proposed using step-wise weight assessment ratio analysis (SWARA) and additive ratio assessment (ARAS) methods [14].

The extensive research conducted on the impact of the COVID-19 pandemic on maritime transportation networks and global supply chains has shed light on the disruptions faced by the industry. The research provides valuable insights to inform policymakers, port operators, and transportation stakeholders in developing effective strategies and policies that foster resilience and stability in the maritime transportation industry. Further research in this area will be pivotal in building adaptive and resilient transportation systems to withstand future disruptions.

## 3. RESEARCH SCOPE AND METHODOLOGY

As the research was focused on the period between COVID-19 onset and recovery, data spanning from January 2019 to August 2022 was collected for study. Assessment parameters included container movements, cargo volumes, ship calls, and various other operational details. Supplementary data was also collected on government policies, economic indicators, and shipping reports. From these, data trends and patterns in container movements and port operations during the pandemic and recovery were developed and correlations identified between various events and port performance. COVID-19 related impacts were quantified in terms of temporal delay and recovery; container movements; cargo handling efficiency; and overall port capacity during various phases of the pandemic.

### 3.1 Data Collection and Analysis

After selecting the ports for study, data for all container ships arriving to and departing from the port was purchased. The data included:

1. marine mobile service identity (MMSI), a unique 9-digit number that is assigned to a ships transponder),
2. UN/LOCODE (the United Nations Code for Trade and Transport Locations) timestamps,
3. move type (arrival or departure), and
4. draught/draft (distance between the ship's keel and the waterline of the vessel).

Data was separated for each port to create four different, though corresponding data sets. Next, each data set was organized by ship arrivals and departures then summed for each day of analysis during the study period. Then vessel dwell times were calculated according to the U.S. Department of Transportation Bureau of Transportation Statistics [44] and, finally, vessel dwell time was calculated using the following equation:

Vessel Dwell Time = Departure Time – Arrival Time (1)

In addition to ship data, the total cargo throughput data was also found for each port. This data is reported in TEU's (twenty-foot equivalent units), which is the measure in units of twenty-foot long containers. All of this data was available on each port's website, with the exception being the Port of Rotterdam which was provided by port administrative authorities.

The vessel dwell time at the ports was analyzed by taking the yearly average dwell time for 2019 and using it as a baseline which would then be used to calculate the relative change in the vessel dwell time for each month from January 2020 to August 2022. This was done for each port separately. The equation used for the calculation is:

Relative change = ((final value – initial value) / final value) *100 (2)

or

% change in dwell time = ((monthly avg, vessel dwell time – 2019 avg. vessel dwell time)/ monthly avg, vessel dwell time)*100

The same process was used to analyze the container throughput at each port.

## 4. RESULTS AND DISCUSSION

Figure 1 below displays the percent change of container throughput at each of the four study ports and the 3 month rolling average. For the first six months of 2020 (January through June), each of the ports saw a decrease if throughput at the port. The Port of Long Beach had a 12% decrease, the Port of New York and New Jersey had an 11% decrease, the Port of Rotterdam had 6% decrease and the Port of Shanghai had an 11% decrease. In July of 2020, each of the ports encountered a considerable increase in throughput. Long Beach experienced a 21% increase in throughput compared to the previous month, New York similarly saw a 19% increase, Rotter had an 11% increase, and Shanghai had an 8% increase in throughput. From this point on through the remainder of the study period (August 2022) Long Beach and New York saw sustained and substantial increases in throughput when compared to 201; the Port of Long Beach had an average of 20% more throughput and the Port of New York and New Jersey had an average of 17% more throughput. Comparatively, the Port of Rotterdam had a 1% increase in throughput, and the Port of Shanghai experienced a 7% increase when compared to 2019.

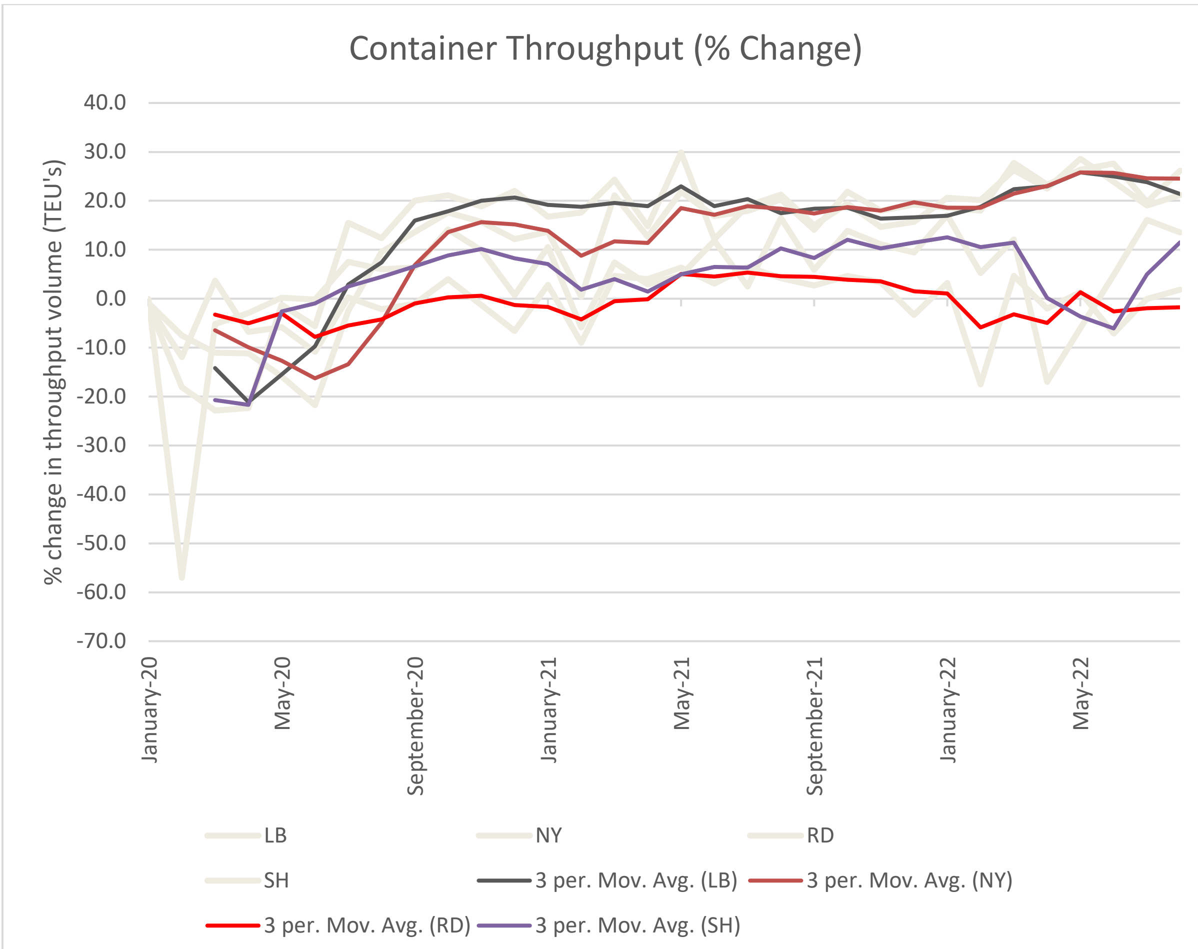


**Figure 1. Percent Change of Container Throughout at all 4 Ports**

Figure 2 below displays the percent change of container throughput at each of the four study ports and the 3 month rolling average. For the first eight months of 2020 (January through August), the Port of Long Beach saw a 12% decrease in vessel dwell time, while the Port of New York and New Jersey had an 9% decrease and Shanghai had a 7% decrease. During this time period, the Port of Rotterdam is the only port see an increase with 11%. Looking at the figure, it is apparent that dwell times started increasing around September 2020, with Rotterdam being the only exception. The increased vessel dwell time in Long Beach and New York can likely be attributed to the increased throughput that started 2 months prior. From September 2020 through August 2022, at the Port of Long Beach the dwell time increased by an average of 31% when compared to 2019. During this same time period, the dwell time at the Port of New York and New Jersey was 18% higher than in 2019, and it was 5% higher at the Port of Shanghai. With a 13%

reduction, the port of Rotterdam is the only port that saw a decrease in their vessel dwell time when compared to 2019. It is reasonable to conclude that the increased throughput at the U.S. ports likely played a large role in the increased vessel dwell times.

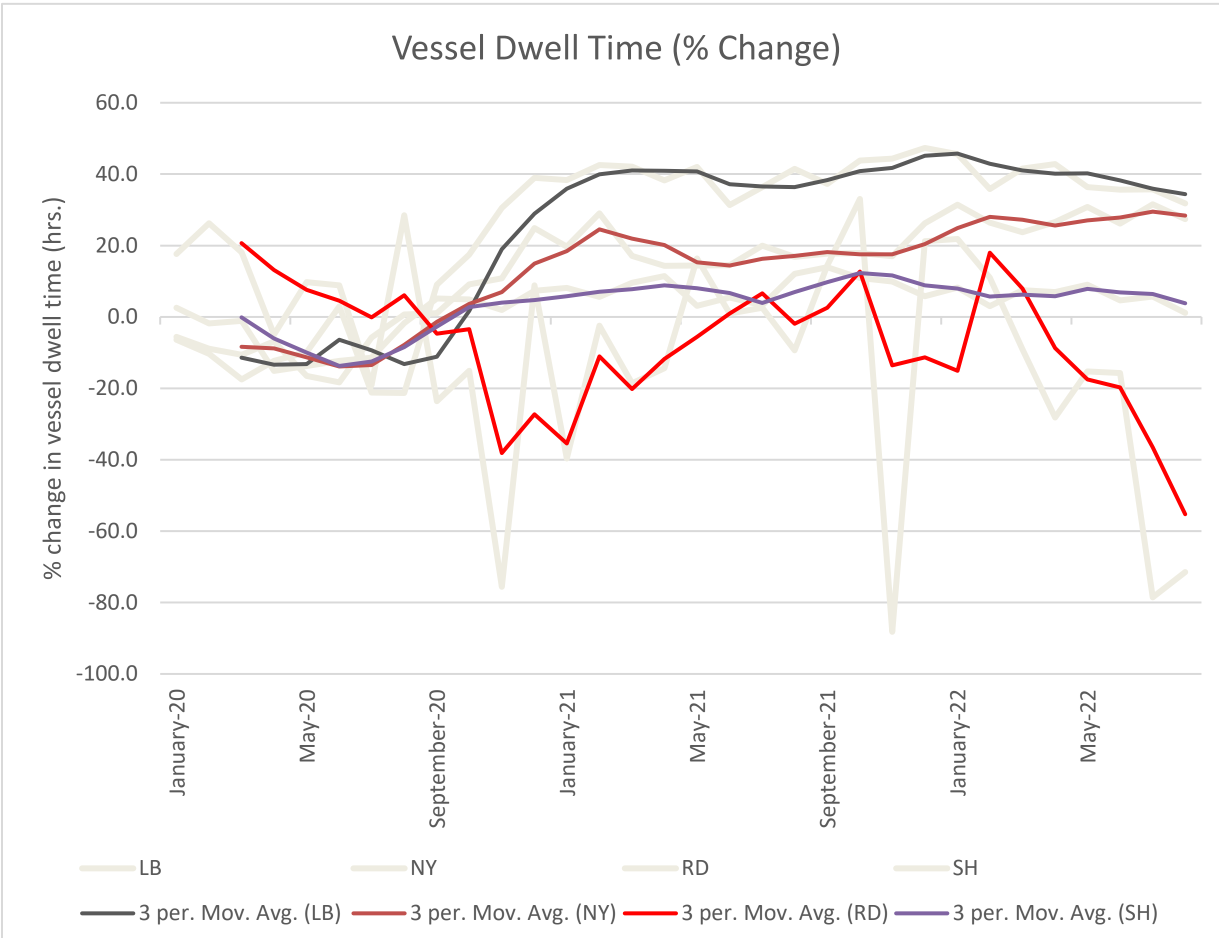


**Figure 2. Percent Change of Vessel Dwell Time at all 4 Ports**

Figure 3 below displays the spending of retail goods in America. Shortly after the disbursement of stimulus checks, spending on retail goods increased. It is reasonable to conclude that the increased spending on retail goods increased throughput at the port, which then lead to increased vessel dwell times.


**Figure 3. Spending on Retail Goods (Courtesy of Board of Governors of the Federal Reserve System)**

## 5. CONCLUSION

As the long-term effects of the global COVID-19 pandemic continue to unfold, research also continues on the more-direct and immediate impacts of the virus (and the governmental restrictions to slow its spread) on various forms of personal and public transportation. In addition to its impact of public health, another of the most significant and lasting impacts of the virus has been on the global economy. Between the social restrictions that limited personal interaction and the temporary closure of schools, entertainment venues, and other employment centers, vast changes have taken place in the fundamental ways in which people now work, shop, attend to school, and vacation.

The pandemic also revealed many of the qualities and shortcomings of the global supply chain that supports the systems that deliver goods around the world. Through decades of international commerce and trade, the world has become dependent on the delivery of merchandise, building materials, and other products from far-away places. Whether in normal times or in a global pandemic, the demand for these goods never changes. Thus, while demand remained constant, if not increased, during the pandemic, the means of production and delivery of these goods have widely ben assumed to have changed dramatically.

The research described in this paper was undertaken to assess two aspect of the global system of goods delivery; vessel operations and container movement in ports. Using data collected at the major global ports of Long Beach, New York and New Jersey, Rotterdam, and Shanghai, the intent of the research was to better understand and evaluate how shipping and containerized shipments varied before and during pandemic and in these cities.

Among the general findings of the research was when, where, and by how much port congestion and delay occurred and changed throughout the crisis. Interestingly, while not all ports were impacted in the same way, changes tended to occur at similar times. In the winter and early spring of 2020, container throughput decreased by about 10 to 12 in all four ports. Similarly, dwell times in the Chinese and American ports decreased between 7 and 11 percent over that same time period, while Rotterdam remained constant. Then, in the summer of 2020, it was apparent that there was a shift in port processes in the US. Container throughput increased by about 20 percent and has effectively remained at that ever since.

Comparing these data parameters to news accounts and other business analytics, the analyses suggest that many of the delays, particularly in the United States, may have been due to an overall shift in consumer spending toward goods from overseas manufacturers and sellers. This significant increase in international containerized shipments is likely what overwhelmed the ports with interruptions propagating throughout the supply system. An examination of the chronology of virus transmission and governmental restrictions also suggests that it likely that limited workforce availability during the various COVID-19 outbreaks contributed to worsening the situation.

Another notable finding was that, in contrast to the United States, the operational performance indicators of this research suggest that the Ports of Rotterdam and Shanghai maintained more-consistent vessel dwell times. While it is not known with certainty, it has been suggested by many that the lack of increased delay compared to the US reflects greater efficiency and resiliency brought by higher level of automaton at overseas facilities. The findings also suggest the vulnerability of US ports to many conditions, including changes in labor availability and consumer spending patterns.

In future research, additional data on workforce availability and productivity can be used to look for causal inferences to the comparatively lower performance at US ports. Simulation models may also be useful to assess variable scenarios, such as consumer spending and workforce availability, enabling better preparedness for congestion issues and supporting the development of resiliency strategies to more effectively manage sudden increases in containerized shipping and safeguard supply chains. Exploring technological innovations like automation and AI may also be helpful to maintain and enhance port operations and capacity to handle fluctuations in cargo volume efficiently. Addressing these opportunities will contribute to building more resilient and efficient global supply chains, capable of withstanding disruptions and supporting sustained economic growth and international cooperation.

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