MARITIME TRANSPORTATION RESEARCH AND EDUCATION CENTER
TIER 1 UNIVERSITY TRANSPORTATION CENTER
U.S. DEPARTMENT OF TRANSPORTATION

Analysis of the Impacts of the COVID-19 Pandemic on Vessel and Cargo Movements in the United States

April 2022 – September 2023

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FINAL RESEARCH REPORT
Prepared for:
Maritime Transportation Research and Education Center

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Acknowledgements

This material is based upon work supported by the U.S. Department of Transportation under Grant Award Number 69A3551747130. The work was conducted through the Maritime Transportation Research and Education Center at the University of Arkansas.

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from the U.S. Department of Transportation's University Transportation Centers Program. However, the U.S. Government assumes no liability for the contents or use thereof.

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Abstract

The Covid-19 pandemic wrought unparalleled disruptions in global supply chains and port operations, unleashing congestion, delays, and container shortages of unprecedented magnitude. As governments worldwide implemented containment measures, shaping social behavior and curtailing economic activity, the repercussions reverberated across ports in the United States. These vital hubs encountered formidable challenges stemming from shifts in demand, labor shortages, and supply chain bottlenecks. Compounding these issues, the surge in e-commerce and disruptive events, such as the Suez Canal blockage, intensified pressures on U.S. ports. The pandemic's impact not only exacerbated existing challenges for ports and supply chains but also triggered inflationary pressures.

This research zeroes in on the profound impact of Covid-19 on port congestion and the global supply chain, with a specific focus on major U.S. ports such as the Port of Long Beach, Port of New York and New Jersey, alongside global counterparts like the Port of Rotterdam and Port of Shanghai. The objectives encompass quantifying shipping volume, identifying trends, analyzing factors, and deepening comprehension for policymakers and stakeholders, crucial in fortifying resilient supply chains.

In the context of U.S. ports, severe congestion emerges as a consequence of heightened consumer spending and an unprecedented surge in container throughput, overwhelming these crucial gateways. The limited workforce availability during Covid-19 outbreaks exacerbates the challenges faced. In stark contrast, the Port of Rotterdam and Port of Shanghai exhibit consistent vessel dwell times, underscoring their efficiency and resilience. The research underscores the vulnerability of U.S. ports to fluctuations in consumer spending, resulting in an inundation of goods and overburdened ports that compromise efficiency and escalate dwell times. Looking ahead, opportunities for improvement involve addressing existing limitations, enhancing data collection methodologies, conducting comparative studies, and exploring technological innovations. These measures are pivotal in constructing more resilient and efficient global supply chains, particularly for U.S. ports, to navigate the uncertainties and challenges posed by future disruptions.

1. Introduction

The eruption of the novel coronavirus disease (Covid-19) marked an unprecedented global upheaval, unseen in over a century [9]. Initially shrouded in mystery, the disease's high fatality rate stirred anxiety worldwide [9]. Swiftly escalating virus transmission strained healthcare systems across nations. In response, various measures were implemented globally to slow the virus's spread and allow healthcare systems to prepare [9]. As the World Health Organization (WHO) declared Covid-19 a pandemic on March 11, 2020, and President Trump declared a national emergency in the United States on March 13, 2020, subsequent actions were taken to curb the virus's impact [1] [2].

The pandemic prompted a cascade of containment measures globally, leading to significant shifts in social behavior and economic activity. The disruptions reverberated through international trade, impacting the global supply chain [9]. This research, focusing on major U.S. ports like the Port of Long Beach and Port of New York and New Jersey, along with global counterparts like the Port of Rotterdam and Port of Shanghai, aims to delve into the repercussions of Covid-19 on port congestion and the broader supply chain.

Amid the multifaceted challenges posed by the pandemic, U.S. ports emerged as focal points, grappling with severe congestion attributed to increased consumer spending and an overwhelming surge in container throughput [9]. Unlike counterparts such as the Port of Rotterdam and Port of Shanghai, which showcased resilience and efficiency, U.S. ports faced vulnerabilities tied to fluctuations in consumer spending [9]. The research spotlights the intricacies of U.S. port dynamics, emphasizing the need to address limitations, enhance data collection, and explore technological innovations to fortify global supply chains.

In the realm of maritime transportation systems (MTS), U.S. ports play a pivotal role, handling 99% of overseas trade and contributing significantly to the national economy [12]. The efficient flow of cargo through these ports is vital for the entire supply chain [11]. Port congestion, especially in U.S. ports like Long Beach, Los Angeles, and Oakland, became glaringly apparent, causing ripple effects worldwide [14]. Shipping bottlenecks and extended wait times for cargo ships, exacerbated by port congestion, became major contributors to the global supply chain crisis.

The surge in e-commerce, amplified by shifts in consumer behavior during the pandemic, added to the strain on ports, leading to increased shipping volumes [18]. The trucking industry, a critical link in the U.S. supply chain, faced challenges due to a severe shortage of truck drivers, further contributing to port congestion [22]. The research underscores how the interplay of these factors, intensified by the pandemic, resulted in disrupted container flows, increased shipping costs, and decreased U.S. exports [27].

As the pandemic unfolded, disruptions extended beyond the shipping industry. Events like the Ever Given blocking the Suez Canal, extreme weather and climate disasters, and a labor shortage in the U.S. further complicated the supply chain [28] [29] [30]. The cumulative impact of these disruptions manifested in increased shipping times, delayed shipping, and inflation [13] [32]. The supply chain's inefficiencies, compounded by disruptions, contributed to inflationary pressures, affecting logistics costs and final product prices.

This research endeavors to quantify the profound effect of Covid-19 on U.S. ports, emphasizing the critical role these ports play in the global supply chain. Analyzing data from the

Port of Long Beach, Port of New York and New Jersey, Port of Rotterdam, and Port of Shanghai, the study explores vessel dwell time as a metric to gauge port efficiency. By comparing findings across these ports, the research seeks to unravel the complexities that fueled port congestion and supply chain complications spanning the three-year period from 2019 to 2022. Ultimately, the goal is to inform future policies and plans, fostering resilience in the face of unforeseen disruptions.

2. Literature Review

Maritime Transport

Maritime transport is a vital link in the global supply chain. With shipping and ports estimated to handle over 80% of global merchandise trade by volume and more than 70% by value, it highlights the economic interdependency that relies upon it. When disruptive factors, like a pandemic, occur, the sector acts like a transmission channel that sends shockwaves across supply chains and regions. The disrupted transportation networks and supply chains can significantly destabilize and weaken economic activity and worldwide trade. Because of this, it is important to understand the various ways that the pandemic affected maritime transportation networks and a great deal of research has been conducted on this subject. The following sections will discuss this research in further detail.

Restrictions put in place to combat the spread of the virus disrupted the global supply chain. The maritime industry experienced a drastic decrease in ship calls, followed by an explosion of demand. Additionally, the industry had to adapt to dynamic conditions in order to continue to operate during the pandemic. The United Nations Conference on Trade and Development (UNCTAD) assessed the immediate impacts of the COVID-19 disruption on the maritime supply chain and trade over the first half of 2020. The assessment observed the impacts of the COVID-19 on the maritime supply chain, the response measures introduced by relevant stakeholders, and implications for the maritime supply chain of the future. The assessment found that the COVID-19 pandemic affected global trade flows at an unprecedented speed and scale. During the first half of 2020, global ship calls were down by 8.7%. When compared to 2019, changes in ship calls were marginal in the first quarter of 2020. However, when countries started to impose lockdowns and restrictions to combat the spread of the virus, there was a 17% decrease in ship calls in the second quarter of 2020. The drop in ship calls varied based on economic classification of the country. When compared to the second quarter of 2019, ships calls in the second quarter of 2020 decreased by 23.1% in developed countries, 9.1% in developing countries, and 10.9% in countries with economies in transition. The United Nations report also included an assessment of the response and risk mitigation measures taken by ports. It found that responses varied and covered different aspects of operations. These include operational adjustments, financial and economic adjustments, sanitary protocols and processes, and adjustments to working practices and organization aspects. Some responses by ports involved a considerable reorganization of operations such as prioritization of essential services, reorganization of operations and working conditions due to sanitary protocols, and the advancement of digitalization and communication strategies. The report also found that existing contingency plans enabled quick responses to the crisis and stakeholders without such plans had to develop plans in a short period. In order to limit personnel shortages, ports adjusted their work practices and allowed telework, rearranged working shifts, limited meetings, and made better use of technology. Initially, many ports managed to avoid major disruptions because of the decrease in maritime trade flow. Finally, it was reported that transport service providers and cargo owners want better forecast prediction and tools to anticipate disruptions and enhance supply chain transparency and flexibility. In addition, ports should be aware of new trade patterns to prepare and adapt infrastructure and operations [11].

Research on maritime mobility by Millefiori et al. was conducted to analyze the short-term effects that the COVID-19 pandemic and containment measures had on global shipping mobility. The study used maritime traffic data collected from Automatic Identification Systems (AIS) receivers and data-driven mobility indexes to quantitatively assess ship mobility in a given unit of time. The global vessel mobility during the first half of 2020 was compared to that of previous years, 2016 to 2019. The research found an unprecedented drop in maritime mobility across all categories of commercial shipping. From March to June 2020, the period in which the most severe restrictions were in force, there is an observable reduction in activity. In general, the study found that shipping mobility was negatively affected, but to different degrees in each market and depending on the size of the vessel [7].

Xu et al. examined the gaps in the shipping trade between China and three other regions during the period of February-October 2020. The study proposed using dynamic panel data to estimate the variances in shipping between China, North America, European Union and Southeast Asia. The paper came to several interesting conclusions. It found that virus prevention efforts and the national macroeconomic situation are linked to the shipping industry. These policies have different effects on the volume of export trade and import trade, and the strictness of government prevention efforts is positively correlated with import trade and negatively correlated with export trade. Additionally, the study concluded that the shipping trades of China, the United States, and the European Union were greatly impacted by the pandemic while Southeast Asia was only slightly affected. The results also show that the shipping trade in China, European Union and Southeast Asia had a significant trend over time, mainly due to the extreme increase in consumption [35].

Zhao et al. studied the affect that the pandemic had on dry bulk and container transportation. An analysis of the Baltic Dry Index (BDI), the China Coastal Bulk Freight Index (CCBFI), and of container throughputs, with and without the impact of Covid-19, was carried out to achieve this objective. The research found that global dry bulk transportation was affected by lockdown policies during the second month of the Covid-19 pandemic. The study also found that the BDI displayed an approximate 35.5% year-on-year decrease from 2019 to 2020. Additionally, the study found that container throughput from 2019-2020 at the Port of Shanghai, Port of Hong Kong, Port of Singapore, and Port of Los Angeles had the largest year-on-year reduction of approximately 19.6%, 7.1%, 10.6%, and 30.9%, respectively. The research also developed exponential smoothing models of BDI, CCBFI, and container transportation to calculate the percentage prediction errors between observed and predicted values to observe the impact of exogenous factors on the shipping industry due to the pandemic. The results of the model are consistent with conclusions acquired from the comparison of BDI, CCBFI, and container transportation during the same period of 2019-2020 [36].

A study conducted by Alamoush et al. sought to investigate the immediate impact of COVID-19 and the ensuing issues for ports, shipping and the maritime supply chains and industry. The participants conducted an exploratory review of various sources. Additionally, the study utilized the findings to conduct a case study to investigate the responses to the pandemic and issues arising at the Port of Aqaba, the only port in Jordan. The report also identified a way forward for ports to follow after the pandemic. The results of the analysis were categorized in to six different, yet interconnected attributes. The study found that ports need to maintain resilience through the pandemic by building risk management plans and expanding the circle of cooperation regionally and globally, not only within the port but also the maritime supply chain. The results of the literature review found that the dynamics of COVID-19 generated severe and unprecedented magnitudes of economic knock-on and delay. It also stated that the pandemic challenged the integrity and reliability of ports, shipping and supply chains. When applied to the case study at the Port of Aqaba, the study found that some issues arose as barriers to shipping; however, there was not a large impact on maritime transport and supply chains. The Port of Aqaba quickly adapted to the pandemic, by providing various facilitation measures such as digital clearance at the ACT. The impact was not sever because restrictions were not imposed on ports. Also, the Port of Aqaba is mostly a final destination port for imported cargo, and there is not a high volume of exports [37].

Guerrero et al. analyzed the change in the maritime network before and after the outbreak Covid-19. The study used AIS data of vessel movements between ports. The results showed a decrease in global maritime connectivity between 2019 and 2020 as well as significant differences between ports and inter-port links. The study also analyzed the effects of COVID-19 mitigation measures on port activity at regional and global levels. It found that mitigation measures did affect regional port hierarchies; however, the effects differed depending on the region. There was an increase in port concentration in Asia and North America and a decrease in Europe and Africa. On the global level the mitigation measures had an irregular impact on ports. The research concluded that large ports resisted better than smaller ports, and small ports fared better when they are highly interconnected with their neighbors. On the other hand, small transshipment hubs and bridges were negatively impacted by mitigation measures [38].

Research conducted by Dirzka and Acciaro sought to understand the manner and extent that the pandemic impaired liner-shipping networks. The study used liner shipping schedule cancellations, which are a serious transport network disruption, as a distress signal of the pandemics impact on the global supply chain. The work assessed first time operational behavior under distress and highlighted disruption clustering and cascading failures in liner shipping networks. Additionally, the research applied a three-stage analysis (network visualization, network description, and network failure simulation) to show how the pandemic imposed a progressively intensifying shock to some geographical clusters while operators tried to preserve network connectivity. Additionally, the study found that agile liner shipping operations and planned service suspensions, helped prevent the collapse of the global maritime transportation network. This indicates the maritime industry’s capability of withstanding major catastrophic events [39].

Guan et al. studied the effects that COVID-19 control measures had on the global supply chain. To do this, the research team analyzed the supply-chain effects of a set of idealized lockdown scenarios using global trade modelling framework. The study modelled the short-term economic shocks of different COVID-19 response scenarios as sector-specific transportation and labor supply constraints. The model used the latest input-output data and took in to account interactions throughout complex global supply chains and the contexts of scarcity and imbalance that occur in most markets. When the model is applied to the simulation of control policies during a pandemic, it can assess the impact of different policies on the supply chain and examine the externalities of control measures. The study found that supply chain losses that were related to initial COVID-19 lockdowns are largely dependent on the number of countries imposing restrictions and the losses are more sensitive to the duration of the lockdown rather than its strictness. Also, a longer containment effort that can eradicate the disease results in smaller losses than shorter ones. However, earlier in the pandemic, stricter and shorter lockdowns can minimize overall losses. The paper also concluded that a 'go-slow' approach to lifting restrictions may reduce overall damages if it helps avoid the need for further lockdowns. Finally, the research concluded that regardless of the strategy, the complexity of the global supply chain will magnify losses beyond the direct effects of the COVID-19 pandemic and pandemic control is a public good that requires collective efforts and support to lower capacity countries [40].

Ports

The role of ports in the global supply chain cannot be understated. It is imperative to understand the adverse impacts that the pandemic and other factors have had on them. The frequency and severity of port congestion as well as port resiliency, flexibility and production have been common subjects of research being conducted. The following sections will discuss this research in further detail.

The impact of the pandemic on port production and operations at the Port of Shanghai was studied using System Dynamics. The objective of the study was to determine the main factors in the port's production and operation system, draw a causal feedback diagram and flowchart of the port's production and operation, and conduct an empirical analysis of the impact of the epidemic on the ports production and operation by simulating three different scenarios (epidemic is aggravated, weakened, and unchanged). The study found that when the epidemic continues like 2020, from 2020 to 2022, the estimated GDP would be reduced by -3.8% (2020), -7.4% (2021), and -10.9% (2022). The impact of COVID on cargo in this period would be a -0.03%, -0.08% , and -0.1%. The impact on passenger transportation is −49.1%, −49.2%, and −49.1%, and the impact on cargo transportation is −10.6%, −20.1%, and −28.6%.When the epidemic is aggravated, from 2020 to 2022, the estimated GDP would be reduced by −3.8%, −7.8%, and −12.0%. The impact on port throughput is −0.03%, 0.2%, and 0.8%. The impact on passenger transportation is −49.1%, −76.5%, and −90.5%, and the impact on cargo transportation is −10.6%, −21.0%, and −30.9%. When the epidemic is weakened, from 2020 to 2022, the estimated GDP would be reduced by −3.8%, −1.8%, and 0.04%. The impact on port throughput is 0.03%, −0.4%, and −1.3%. The impact on passenger transportation is −49.1%, −32.7%, and −7.8%, and the impact on cargo transportation is −10.6%, −6.8%, and −2.0%. Lastly, the study found that passenger transportation was most impacted by the epidemic, and the impact on ports that dominate cargo transportation is relatively small [41].

Osundiran et al. studied the impact of the pandemic on port production and efficiency at the Port of Singapore. The research examined the efficiency of the port along with the drivers of productivity, assessed the trends in cargo throughput and vessel visits, and examined the measures put in place to mitigate the impact of the disease. Descriptive statistics was used to analyze the trends in container throughput for the years 2010-2020, and the Malmquist Productivity Index Data Envelopment Analysis (MPI-DEA) was used to analyze the efficiency of the port. The study found that the port productivity levels in 2020 were consistent with pre-pandemic levels and that the drivers of productivity were efficiency and technology. Additionally, a close examination of vessel visits found a decline in all types of commodities. Finally, the paper found that the port put measures in place to limit the spread of COVID and its impact on port operations. These measures included engagement of the port stakeholders early on and continuously, temperature screening at sea checkpoints, health questionnaires, updates on affected regions and quarantine for those that contracted the virus on-board the vessel [42].

The increase in frequency and severity of port congestion is one of the many contributors to recent global supply chain issues. Research conducted by Gui et al. sought to reduce the adverse impacts of congestions risks. The study sought to develop new risk analysis methods in order to assess uncertainty associated with the COVID-19 pandemic as opposed to the common port congestion risk scenarios that traditional analysis techniques evaluate. The research resulted in a model designed for the identification and prioritization of port congestion risk during the pandemic. A case study and sensitivity analysis were conducted and the model was validated. The outcome verified that the method is functional and feasible, and the findings may provide insights in to risk prevention and mitigation at ports [43].

Research by Russell et al. sought to enable flexibility in port logistics so that ports can better navigate uncertainties and disruptions. In order to accomplish this, they developed a conceptual framework to fully understand the various elements of capacity and the interplay among the logistics triad of transport carriers, port operators, and logistics service providers. The study found four dimensions of port logistics capacity; seaside interface, platform, landside interface, and system-wide. The paper states that each of these categories contains sub-elements that are either static or adjustable. The authors state that, "Flexibility in static components relies on expansion mechanisms, while flexibility in adjustable components relies on adaptive mechanisms to improve the utilization of existing capacity." Additionally, the framework that was developed may provide insights in to the logistics triad roles and identify levers to build flexibility in to interrelated capacity elements [44].

In November 2021, the Congressional Research Service issued a report on supply chain bottlenecks at U.S. ports. The report states that retail sales in the U.S. were 20% higher from March through July 2021 than for same period in 2019. This led to a surge in containerized cargo because many of these goods are manufactured in Asia. At the time of the report, dozens of ships were waiting to unload at the ports of Los Angeles and Long Beach. Port operators in the U.S. expressed concerns regarding the U.S. Customs and Border Protection's (CBP) ability to process the large volume of incoming cargo. The report states that the CBP was taking steps to alleviate these concerns; these include reallocating field officers from passenger to cargo operations and forming the Covid-19 Cargo Resolution Team to expedite the clearance of personal protective equipment across U.S. ports of entry. Additionally, there was a 90-day postponement of certain duties, taxes, and fees for importers experiencing significant financial hardship. The report also spoke to inefficiencies in port operations. It stated that a truck driver shortage was contributing to supply chain problems and ports truckers were seeking easier interchange of container and chassis equipment [20].

A research study conducted by Komaromi et al. for the International Monetary Fund (IMF) sought to shed light on the long delays that port congestion may have caused in delivering goods. The study utilizes algorithms developed by Cerdeiro, Komaromi, Liu and Saeed (2020), to translate ships radio messages from AIS into port-to-port voyages and estimates of corresponding trade volumes. By applying this method, and tracking virtually every cargo ship in the world, a granular picture of world sea trade emerges. The study then uses this information to provide facts on the extent and geographic distribution of port delays. The first finding of the paper is that shipping times jumped upwards as soon as the COVID-19 crisis hit. Starting at the end of 2020, the delays then began to accelerate and surpassed 1.5 days on average in December 2021. The research also concluded that two-thirds of this delay was due to ships waiting longer at anchor before entering the port, and one-third was caused by slower cargo processing at the berths. The second finding of the paper is that there was a substantial geographical variation in port delays. The most severe port congestion was concentrated in the United States and China. Additionally, there is variability in delays at the port level. For example, the Port of Los Angeles is an outlier among major ports both in terms of longer wait times at anchorage and in terms of slower processing times at berths. These slow turnaround times may suggest that not only more ships are arriving at the port, but supply bottlenecks prevent efficient cargo processing [13].

A study conducted by Su et al. collected and analyzed data from the Port of Shanghai to determine the influence of COVID-19 on the commodity category of port export in China. The study compared the data collected from January to May 2020 to the same period in 2019. The paper discusses major commodity categories affected by the pandemic, and offers countermeasures based upon its findings to stabilize the quantity of the category and reduce the risk of lower port trade volume of the export commodity category in the future. The research concluded that the efficiency of Shanghai port logistics is low and has long management links. The main reason being a lack of an information sharing platform and that information resources cannot be shared among various departments. In order to counteract this, the paper suggests the construction of unified network system that integrates all relevant port departments. The research also found that there is a large gap in the proportion of each export commodity at the port. This is not conducive for dispersing risks. The export structure at the Port of Shanghai is mainly based on high-tech and electromechanical products, and other commodity trading is relatively small. The study suggests combining the export quantity of all kinds of goods to avoid imbalance. Finally, the study found that the high environmental cost of enterprise affects the sustainable development of port enterprises. The paper suggests sustainable development of the port to create sustainable development in all aspects of port production and management. Additionally, to achieve sustainable development of the port economy, the use of energy and raw materials to integrate with the surrounding environment is essential [45].

Notteboom et al. investigated the temporal and spatial sequences of the supply and demand affects of the COVID-19 pandemic on container ports and the container shipping industry. The study compared these events to the 2008-2009 financial crisis. To accomplish this objective, the researchers analyzed operational and financial data from primary and secondary resources to observe short-term impacts, differences, reasons for variations, and the evolution of adaptive capacity and resilience of ports, terminal operators, and carriers. The analysis focused on the impacts on global supply chains, impacts on operational aspects, market structure, strategic behavior of shipping lines and terminal operators, impacts on port vessel calls and container volume, and the changes in container port connectivity. The study found that warning signs of the crises varied within the shipping industry. With the financial crisis, shipping and related markets ignored warning signs, while the COVID-19 pandemic was an external shock with few short-term warning signs. This shows that, although the financial crisis and the pandemic may have had similar impacts, these impacts do not show similar patterns across ports and shipping networks. The research study also identified several differences in the shipping industries resilience during the two crises. During the financial crisis, the shipping lines could not effectively manage their collective capacity; this led to rate erosion, poor vessel utilization, and bailouts. During the pandemic, shipping lines reconfirmed their market position and bargaining power, this led to an upsurge in freight rates and a positive effect on financial results. Overall, the changes observed and strategic behavior of the market players reveal that adaption mechanisms were applied differently between the two crises, which resulted in different outcomes [46].

Research conducted by Abous et al. tried to measure the impact of the COVID-19 pandemic on container transport in Morocco. The study targeted the Tanger Med container port due to its geographic position as the most important link between Africa and Europe. The objective of the research was to observe how COVID-19 figures affected the quantities of goods measured in twenty-foot equivalent units (TEU's) within the Tanger Med port. The research focused on the period of March 21, 2020 to April 30, 2020. The analysis showed that the pandemic had a negative and significant impact on container transport operations with the port. At the end of March 2020, the port activity decreased by 1.2%, which represents 4.8 million tons of cargo. The study concluded early on in the pandemic and states that the data mainly reflected the situation in China. At the time, it was also expecting a decrease in imports as the pandemic had Italy, who exports many goods to Morocco was in lockdown [47].

Bosco et al. reviewed existing literature to understand the impact of port disruption on the maritime supply chain. The article reviews the existing agents on the maritime supply chains and the economic impact, and literature on port resilience. The paper found that, when compared to other disruptive agents in transportation systems, there is only a small number of studies about port disruption. The paper also found that several researchers have proposed qualitative frameworks and strategies to address port vulnerabilities and improve maritime supply chain resilience. The review also found that even though there are quite a few quantitative port resilience methodologies, no research considered more than a few possible resilience actions. Finally, the paper states that it is evident that maritime supply chain intermodal resilience modeling is in its early stages and has ample room for improvement [48].

The Port of Gothenburg, the largest in Scandinavia, was studied by Svanberg et al. to assess the impact of disruptive events on port performance and choice. The study analyzed AIS data along with port statistics on container handling in the four main container ports in Sweden from 2014-2018. The research focused on the relationship between container volumes handled and calculated performance metrics at specific times of intense labor disputes at the Port of

Gothenburg during the second quarter of 2016, and from the fourth quarter of 2016 through the second quarter of 2017. The research found that the decline in container volumes handled at the port over these periods is due to fewer ship calls following each of the periods of labor disputes. Additionally, the study showed that production at the Port of Gothenburg was at its lowest level towards the end of the period of intense labor conflicts. Finally, the paper concluded that the 3 other container ports in the region saw a significant increase in throughput of container traffic; a result of increased average volume handled by each ship [49].

Ports are susceptible to the physical impacts of natural disasters since they are located in low-lying coastal and riverine areas. Verschuur et al. conducted research to understand how disruptions from natural disasters affect port and logistics resilience. The study built upon previous analyses (Farhadi et al., 2016, Tzouinsky et al., 2018) and utilized ASI data to provide empirical evidence of vessel movements in and around ports affected by and unaffected by natural disaster. The research analyzed 141 incidents of disruption across 74 ports and 27 disasters. The results of the study show a median disruption duration of 6 days with a 95th percentile of 22.2 days. The analysis also found that multiple ports are affected simultaneously; this challenges studies that focus on single port disruptions. Finally, the study found that the duration of the disruption scales with the severity of the disaster. A 1.0 meter increment or 10 m/s wind speed is associated with a two day increase in disruption duration [50].

Research conducted by Caballini et al. analyzed customs and port data in order to gain insight in to how the pandemic affected selected logistics flows passing through the ports of Genoa and Savona. Additionally, the research aimed to highlight mitigation strategies that were put in place during the pandemic. The research focused on three significant supply chains that pass through the aforementioned ports. The study found that the pandemic strongly affected the observed supply chains, and that each supply chain reacted with varying degrees of resiliency by employing mitigation strategies that allowed operations to continue. Big data analytics was vital to increasing supply chain resilience as it increased the ability to provide real-time information to and between stakeholders [51].

Wang et al. quantified the impact of COVID-19 on ship visiting behaviors to ports. The study proposed a framework to analyze the impact of COVID-19 on port traffic using AIS data. A behavior-based model for ship travel was proposed to identify anchoring and berthing. Next, the diversity in vessel anchoring and berthing time were analyzed; this reflects the impact of COVID-19. Finally, the port congestion caused by the pandemic is quantified by accounting for the number of visiting ships and their residence time. Once the analysis was completed a case study was carried out on vessels in Beibu Gulf, China from 2019 to 2020. According to the results, anchoring times increased by 62% and berthing times increased by 11% for cargo ships after the outbreak. Additionally, the research results show that the level of port congestion at the study port increased after the pervasiveness of COVID-19. This manifested as an increase in the number of anchored ships and prolonged ship waiting time. Port congestion is generally caused by an increase in the number of ships arriving at the port in a short time or a decrease in the efficiency of port operations. The experimental results show that there was no significant change in the number of ships arriving at the Port of Qinzhou after the outbreak, therefore it can be inferred that the reduction of efficiency contributed to the port congestion [52].

A study conducted by Hanson et al. sought to rank port cities with high exposure to climate extremes. The goal of the study was to take a preliminary global overview of coastal flood exposures for the worlds largest port cities around and produce rankings based on the population and asset exposure to current and future extreme water levels. The investigation was an elevation-based GIS analysis based on McGranahan et al. (2007). The paper, published in 2009, concluded that about 40 million people are exposed to a 100 year coastal flood event. Asset exposure in these cities, in 2005 dollar values, was $3 trillion, or 5% of global GDP. The paper also concluded that by 2070, the total population exposed could grow to more than threefold and asset exposure could top 9% of global GDP [53].

Loh et al. measured the impact of port-related threats on supply chains in order to shed light on the cost consequences associated with them. The study compared four consequences of an example of these threats; avoidance of disruption, mitigation and disruption, deviation of transportation plan, and delays and deviation of transportation plan. The impact of the consequences is then applied to a case study that used data from a chemical manufacturer. The findings of the paper highlight the importance of port related supply chain disruption management. The paper concluded that better dissemination of information from ports to their stakeholders is necessary as well as a closer collaborative working relationship between ports and their users [54].

Supply Chain

While the COVID-19 pandemic led to a sharp worldwide economic downturn, the U.S. economy rebounded rapidly and began to overheat. This has resulted in the highest inflation rate in thirty years. The strained global supply chain has been targeted as one of the main culprits for the inflation. Shipping costs and delivery delays increased substantially, inventories are reduced, and many manufacturers have had difficulty getting key production inputs. While there is no consensus on the degree to which disrupted supply chains account for increased inflation, a lot of research has been conducted to better understand the relationship. The following sections will discuss this research in further detail.

Research by di Giovanni et al. sought to quantify how the distinct aspects of the COVID-19 shock impacted the flow of goods across countries as well as their prices. In order to do this, the authors provide three distinct model-based quantitative exercises. First, the research built upon previous theoretical work to quantify the effects of the pandemic on inflation over the period spanning the collapse and recovery phases of the economy. Next, the research utilizes a previous approach to multi-country framework from Baqaee & Farhee (2022) to capture the importance of international spillovers in generating inflation. Lastly, the research examined how observed cross-country and cross-sectoral consumption changes spilled over across countries via the global production network. The research found four key results. First, compositional effects, or the switch from services to goods consumption, are amplified through global input-output links, which affect both trade and inflation. Second, inflation can be higher under sector specific labor shortages relative to a scenario with no such supply shocks. Third, global supply chain bottlenecks and foreign shocks played a large role relative to domestic aggregate demand shocks in explaining euro area inflation over 2020-2021. And lastly, international trade did not respond to changes in GDP as strongly it did during the financial crisis of 2008-2009, despite a strong demand for goods [55].

Santacreu and LaBelle investigated the role that supply chain disruptions during the COVID-19 pandemic played in U.S. producer price index (PPI) inflation. The research found that the exposure to foreign bottlenecks through global value chains (GVCs) played a significant role in transmitting the effects of supply chain disruptions to U.S. prices. It also found that industries that rely upon inputs from countries that were heavily disrupted also experienced large price increases due to the inability to keep up with demand. Finally, the paper states that the ability of supply chains to ease in order to meet higher demand will determine whether inflation caused by supply chain disruptions is temporary or permanent [56].

In June of 2021, a U.S. subcommittee on Coast Guard and Maritime Transportation met to discuss the impacts of shipping container shortages, delays, and increased demand on the North American supply chain. In the transcript of the hearing, the committee states that the shift to work from home resulted in a significant increase in online shopping. This heightened demand for imported goods and commodities, which are primarily produced in Asia, along with periodic labor shortages due to COVID outbreaks, has fueled a massive backlog and price increase in the shipping container market. Additionally, the increased flow of goods has primarily been from China, to the United States which has resulted in port congestion, especially on the west coast of the U.S. As a result, many carriers chose to ship empty container back to Asia, rather than carry U.S. exports since it is more profitable to do so. This led to a massive imbalance in the shipping market; in June 2021 container rates from Los Angeles to Shanghai were $779, while costs from Shanghai to Los Angeles were $5,952. The shortage of containers placed a heavy strain on agricultural exporters in the U.S. and left them without access to international markets, and no guarantee that their product will be delivered on time. The situation has also affected dock workers who are doing all they can to keep up with the demand; these port workers have also been exposed to numerous outbreaks of COVID. The delays are costly, not only in time, but also in the application of detention and demurrage fees for lengthy container storage times on ships and docks [57].

Research to determine the issues caused by the shortage of empty containers and rank alternative solutions was conducted by Toygar et al. The study utilized the step-wise weight assessment ratio analysis (SWARA) method to rank criteria representing the problems, and the additive ratio assessment (ARAS) method was used to rank alternative solution methods. These two methods are compatible with each other, are simple in terms of mathematical operations, have high reliability, and simple output. Four main criteria and sixteen subcategories were used to define the problems. Also, a multi criteria decision model, which comprised of five criteria solutions, was proposed based on information from literature, sectorial publications, and expert opinions. The study ranked the four problems caused by the container shortage during the COVID-19 pandemic as cost increase in container transportation, supply chain uncertainty, volume loss in container transportation, and increased blank sailing. Additionally, the study ranked the five solutions as shipping guarantee booking, information communication technologies, shipper owned container, inducement calls, and end-to-end delivery services [25].

Tauber and Van Zandweghe studied why durable goods spending was so strong during the pandemic. The paper states that durable goods spending typically slows gradually for a year after a business cycle peak. In the case of the pandemic, spending briefly contracted severely, but rose sharply thereafter. The study utilized an econometric model to understand wat accounted for this unusual behavior during the pandemic. By understanding the factors behind the rise in durable goods spending, policy makers can be better informed and make better assessments of pandemic policy responses. The study explores two possible explanations for the increased spending. The first explanation is that lockdowns and social distancing shifted consumer demand away from services toward durable goods. The second possible explanation is that fiscal policy measures led to disposable income which then stimulated consumption expenditures. The researched used a panel regression that related the growth in durable goods to the state's growth in personal income. The study found that altered consumer tastes and increased disposable income were two important factors, although monetary policy may have contributed by fostering favorable financial conditions. Additionally, the paper states that the importance of these factors is likely to fade and become more similar to the historical mix of durable goods, non-durable goods, and services [18].

3. Research Objectives and Scope

Objectives

The primary focus of this research is to extensively analyze the impacts of the COVID-19 pandemic on key ports in the United States and globally, with a specific emphasis on the Port of Long Beach and the Port of New York and New Jersey. The research objectives include:

This research will:

1. Quantify shipping volume, dwell times, and container throughput at the aforementioned ports;
2. Look for trends at these ports;
3. Seek explanations for the trends;
4. Increase our understanding of the effect that the COVID-19 pandemic had on port congestion.

Scope

This project examined the role that container shipping had in supply chain issues during the Covid-19 pandemic. The scope of the project was to analyze local Covid case data and data which contained information about container ship arrivals, departures, and the associated timestamps as well as container throughput at two selected ports in the United States, while also investigating two major foreign ports, for comparison purposes. The period for the data was from January 1, 2019 to August 22, 2022.

4. Research Methodology

The following tasks were performed to achieve the objective of the research project: 1. Port Selection, 2. Data Collection & Analysis.

Port Selection

The following four ports were selected for analysis because of their locations and their significant role in the global supply chain.

Port of Long Beach

The Port of Long Beach, located in Long Beach, California, is considered the U.S. gateway for trans-Pacific trade. The port handles trade valued at $200 billion annually. It supports 2.6 million jobs across the nation, 575,000 jobs in Southern California and 50,000, or 1 in 5, in Long Beach. It is one of the few U.S. ports that can handle the largest shipping vessels in the world. The port serves 175 shipping lines with connections to 217 seaports around the world. Goods that move through the Port of Long Beach originate in or are destined for every congressional district in the U.S. [58]. Each year the port handles more than 9 million twenty-foot container units (TEUs), 78.5 million metric tons of cargo, and 2,000 vessel calls. The ports loaded containers account for 20% of cargo moving through all U.S. ports. The port comprises 3,520 acres of land, 4,600 acres of water, 10 piers, 80 berths, and 72 post Panamax gantry cranes. The port is ranked the 2nd-busiest in the U.S. and the 21st-busiest container port in the world. The Port of Long Beach, along with the Port of Los Angeles, generates $5 billion a year in U.S. Customs revenues. It also generates $46.6 billion in local, state and federal tax revenue, $374 billion in direct and indirect business sales yearly, and $126.8 billion in annual trade-related wages. East Asian trade accounts for more than 90% of the shipments through the port. The top trading partners for imports by TEUs are China, Vietnam, and South Korea. The top trading partners for exports by TEUs are China, South Korea and Taiwan. The top imports at the Port of Long Beach are crude oil, electronics, plastics, furniture and clothing. The top exports are petroleum coke, petroleum bulk, chemicals, waste paper and foods.

Figure 1: Port of Long Beach (photo courtesy of Don Ramey Logan)

Port of New York and Jersey

The Port of New York and New Jersey is the largest port on the east coast and the third largest in the nation. In 2019, the port moved over 7.4 million TEUs of cargo. The port is considered a gateway to the largest consumer market in North America. The port contains six state-of-the-art container terminals that can handle nine 14,000 TEU vessels at the same time. There is one billion square feet of warehousing and distribution space within 50 miles of the ports [59]. In 2019, the port accounted for nearly $12 billion in tax revnue, 500,000 jobs, and was responsible for $36.1 billion in personal and $99.5 billion in business income [60]. In the same year, over 86 million tons of cargo passed through the port with an estimated $205 billion in value. In 2019, the top trading partners for imports was China, India, and Italy. In 2019, the top trading partners for exports was India, China and Germany. The top imports of containerized cargo at the Port of New York and New Jersey was furniture, machinery, plastic and beverages. The largest export of containerized cargo was wood pulp, vehicle parts, plastic, and wood & aticles of wood [59].

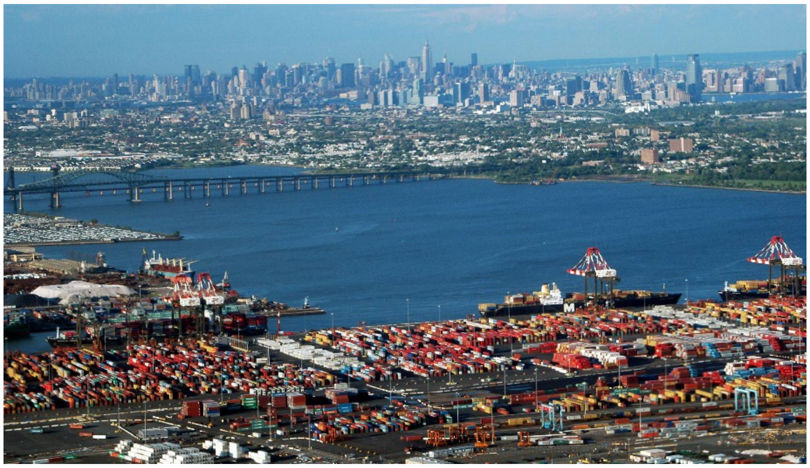


Figure 2: Port of New York and New Jersey (photo courtesy of Maureen)

Port of Rotterdam

The Port of Rotterdam is located in the city of Rotterdam in the Netherlands. It is the largest seaport in Europe and the largest seaport outside of East Asia. The port supports 565,000 direct and indirect jobs throughout the Netherlands, and approximately 175,000 of those jobs are directly related to the port. In 2021, the port handled 325.2 million metric tons of import cargo, and 143.5 million metric tons of exports. The port saw 28,876 sea-going vessels, and handled over 15 million TEUs. The port added a value of €23.8 billion in 2020, which is 3% of Dutch gross domestic product (GDP). The port area is 12,464 hectares (ha) and 4,498 ha of water area. It also contains 1,500 km of pipelines [61]. The Port of Rotterdam has 122 jetties, 23 berths, 6 pilot boats and 29 tugboats. There are over 90 terminals, 35 for liquid bulk cargo, 15 for dry bulk cargo, and 17 for multi-purpose use. The cargo handling equipment at the Port of Rotterdam includes 10 sheer leg cranes, 12 container cranes, 22 ship-to-shore bulk cranes, 25 floating cranes, 103 container gantry cranes, and 162 multi-purpose cranes [62].


Figure 3: Port of Rotterdam and Nieuwe Waterweg (Photo courtesy of Dicklyon)

Port of Shanghai

The Port of Shanghai, located in Shanghai, China, is the busiest port in the world in terms of cargo tonnage. It has handled the most container throughput in the world for 13 years straight. The Shanghai International Port Group (SIPG) is responsible for operating and managing the terminals at the port. The port is comprised of a deep-sea port and a river port and it covers an area of 3,619 km^2 [63]. The Port of Shanghai faces the East China Sea to the east, Hangzhou Bay to the South, and it includes the confluences of the Yangtze, Huangpu and Qiantang rivers. The port mainly handles coal, metal-ore, petroleum and petroleum products, steel, and machinery equipment. The port serves 281 shipping routes, and covers the most important global links [64]. In 2022, the port throughput exceeded 47.3 million TEUs [65]. In 2021 the port employed 13,550 people. The Port of Shanghai is made up of several separate ports. Wusongkou, Waigaoqiao and Yangshan are the three main container port areas and the container terminals have over 13km-long quay length, 43 berths and 156 quay cranes.

Figure 4: Port of Shanghai (Photo courtesy of fuyu liu/Shutterstock)

Data Collection and Analysis

After the ports to be studied were determined, a collection of Covid-19 timeline information was compiled for each city. This information included the new daily Covid cases for each city or county, dates of mandatory stay at home orders, first Covid deaths, relaxing of restrictions, phased re-openings, renewal of stay at home orders or mask mandates, and dropping of all restrictions. In order to do this, executive orders, city press releases and news articles were compiled to create a timeline for each port city. The data reporting daily new cases of Covid was generally found on the Department of Health website associated with the city, county, or country with the exception being Shanghai.

After the timeline data was collected, the data for all container ships arriving to and departing from the port was purchased. The data begins on January 1, 2019 and stops on August 22, 2022. The data includes the marine mobile service identity (MMSI, a unique 9-digit number that is assigned to a ships transponder), port name, UN/LOCODE (the United Nations Code for Trade and Transport Locations), a timestamp, move type (arrival or departure), and the draught/draft (distance between the ship’s keel and the waterline of the vessel).

Table 1: Shipping Data used for Analysis

MMSI	PORT NAME	UNLOCODE	TIMESTAMP UTC	MOVE TYPE	DRAUGHT (METERx10)
565936000	SHANGHAI	CNSHG	1/1/2019 0:00	DEPARTURE	97
218776000	SHANGHAI	CNSHG	1/1/2019 0:05	ARRIVAL	121
352042000	SHANGHAI	CNSHG	1/1/2019 0:05	DEPARTURE	71
636018572	LONG BEACH	USLGB	1/1/2019 0:11	DEPARTURE	110
636016231	SHANGHAI	CNSHG	1/1/2019 0:12	DEPARTURE	118
477194400	SHANGHAI	CNSHG	1/1/2019 0:16	ARRIVAL	145
229452000	SHANGHAI	CNSHG	1/1/2019 0:17	ARRIVAL	106
563032900	SHANGHAI	CNSHG	1/1/2019 0:29	ARRIVAL	107
413369010	SHANGHAI	CNSHG	1/1/2019 0:34	ARRIVAL	50
477271300	SHANGHAI	CNSHG	1/1/2019 0:34	ARRIVAL	105
477770700	SHANGHAI	CNSHG	1/1/2019 0:40	ARRIVAL	96
477680400	SHANGHAI	CNSHG	1/1/2019 0:43	DEPARTURE	60

After collecting the data, it was separated according to the port so that there were four separate data sets. Next, each data set was organized by ship arrivals and departures. The ship arrival data for each port was then summed according to the day so that the total number of ships arriving at each port was known for each individual day from January 1, 2019 – August 22, 2022. The same procedure was done for the departing ships.

Next, the vessel dwell time was calculated. According to the U.S. Department of Transportation Bureau of Transportation Statistics, vessel dwell time is the amount of time that vessels spend in port actively loading or unloading cargo [66]. The vessel dwell time was calculated by organizing the data by the ships MMSI, arrival time and departure time so that a ships arrival in to port and departure from the port could be seen. The vessel dwell time was then found by the following equation:

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

Once the vessel dwell time for each ship arrival/departure was known, the monthly average dwell time for each port was calculated for every month in the study period.

Table 2: Example of Calculated Dwell Time

MMSI	PORT NAME	UNLOCODE	MOVE TYPE	DRAUGHT (METERx10)	Timestamp	Dwell Time(Hours)
205118000	NEW YORK	USNYC	ARRIVAL	105	9/17/2021 10:47	
205118000	NEW YORK	USNYC	DEPARTURE	85	9/19/2021 0:35	**37.80**
209087000	NEW YORK	USNYC	ARRIVAL	124	6/11/2021 8:31	
209087000	NEW YORK	USNYC	DEPARTURE	105	6/13/2021 2:11	**41.67**
209087000	NEW YORK	USNYC	ARRIVAL	95	6/22/2021 20:59	
209087000	NEW YORK	USNYC	DEPARTURE	98	6/24/2021 6:36	**33.62**
209087000	NEW YORK	USNYC	ARRIVAL	131	8/6/2021 7:18	
209087000	NEW YORK	USNYC	DEPARTURE	97	8/7/2021 15:33	**32.25**

In addition to ship data, the total cargo throughput data was also found for each port in the study. Generally, this data was found on the port website, with the exception being the Port of Rotterdam, where the data was requested and provided by the Port of Rotterdam. The total cargo throughput is the total amount of shipping container volume in TEUs (measurement based on the volume of a 20-foot long by 8-foot wide metal container; there is not a standard height to the containers, but the most common height is 8.5 feet long.) that are inbound and outbound at the port. The total cargo throughput does include empty inbound and outbound containers. The Port of Long Beach and Port of New York and New Jersey, report the amount of empty containers along with loaded containers per month as well as inbound and outbound units, as shown in Figure 7. The throughput data for the Port of Rotterdam and the Port of Shanghai only reports the total throughput per month, as shown in Figure 8.

Table 3: Throughput Data for the Port of Long Beach

Date	Loaded Inbound	Empty Inbound	Total inbound	Loaded Outbound	Total Loaded	Empty Outbound	Total Empties	Total
January-19	323,838	6,290	330,128	117,288	441,126	209,870	216,160	657,286
February-19	302,865	5,734	308,599	105,287	408,152	182,731	188,465	596,617
March-19	247,039	9,033	256,072	131,436	378,475	165,313	174,346	552,821
April-19	317,883	6,713	324,596	123,804	441,687	179,721	186,435	628,122
May-19	290,568	4,887	295,455	120,577	411,145	157,592	162,479	573,624
June-19	331,617	6,221	337,838	133,833	465,450	205,497	211,718	677,168

Table 4: Throughput data for the Port of Shanghai

Date	Total Container Throughput
January-19	3752000
February-19	2855000
March-19	3805000
April-19	3612000
May-19	3756000
June-19	3756000

The analysis used vessel dwell time as a metric to observe port congestion. Port congestion means that ships arrive at the port and cannot load or unload, as the terminal is already full. The variables of local Covid cases, ship arrivals/departures, and container throughput were then observed in relation to the vessel dwell time at each port in an attempt to understand the cause of port congestion. The findings at each port were then compared to one another to observe the variability in efficiency at the different ports throughout the pandemic.

5. Results

The results section is organized by each port. First, an overview of the Covid timeline is provided for each port city or county as well as a display of the new daily Covid cases occurring. Next, the 30-day moving average for vessel dwell time for ships and the 30-day moving average of new Covid cases was analyzed to observe the relationship between viral spread and port congestion. Afterwards, the 30-day moving average for arrivals, departures and vessel dwell time at the port was analyzed to determine if port congestion was influenced by an increase in ship arrivals and departures. Finally, the monthly average dwell time and the monthly total container throughput in TEUs was analyzed to observe the relationship between cargo quantity and port congestion.

Port of Long Beach

Covid Timeline

The city of Long Beach, California, located in Los Angeles County, has a population of 451,307 people [67]. Before the pandemic, Long Beach had public health infrastructure designed to address outbreaks and epidemics and the city worked with the LA County Department of Public Health to stay coordinated and informed. The following is a summary of the Covid-19 related government orders as well as some key miles stones experienced in Los Angeles (LA) County, CA over course of the study period. Figure 9 illustrates 30-day moving average of new Covid-19 cases in LA County as well as 30-day moving average for vessel dwell time for ships at the Port of Long Beach, for reference.

- January 2020: the Long Beach Department of Health and Human Services began monitoring the outbreak of Covid-19 [68].
- March 9, 2020: The City of Long Beach Public Information Office releases a press release announcing the first positive cases of Covid-19 [69].
- March 11, 2020: LA County announces its first Covid-19-related death [70].
- March 16, 2020: LA County Health Officer issues an order to prohibit large gatherings, require social distancing, and temporarily close certain businesses [70].
- March 19, 2020: Governor Gavin Newsom issues a statewide stay-at-home order for California [71].
- May 8, 2020: Governor Newsom issues the first phase of reopening guidance for low-risk retailers [72].
- May 29, 2020: Phase 2 reopening begins in LA County, including barber shops and restaurant dining rooms with modifications [72].
- June 26, 2020: Outdoor dining expands in LA County [73].
- August 7, 2020: LA County exceeds 200,000 Covid-19 cases [74].
- August 12, 2020: LA County reaches 5,000 Covid-19-related deaths [74].
- September 5, 2020: LA County surpasses 6,000 Covid-19-related deaths [74].
- November 17, 2020: Governor Newsom issues a mandatory mask-wearing order for the entire state [74].
- November 27, 2020: LA County issues new stay-at-home orders, closing non-essential businesses and limiting gatherings [75].
- December 13, 2020: First Covid-19 vaccines from Pfizer arrive, and healthcare workers in LA County receive them [76].
- January 4, 2021: LA County reports a record 21,944 new Covid-19 cases in a single day [76].
- January 25, 2021: State health officials lift all regional stay-at-home orders.

- Late February 2021: Hospitalizations in LA County decrease by nearly 80 percent from the peak seen in the prior month.
- April 18, 2021: LA County reports its lowest Covid-19 positivity rate since the beginning of the pandemic.
- June 15, 2021: California drops pandemic restrictions and returns to nearly all pre-pandemic levels of activity.
- August and September 2021: Surges in new Covid-19 cases due to the Delta variant [76].
- August 4, 2021: LA County reports the highest uptick in cases with 4,242 new cases reported [76].
- January 4, 2022: LA County sees 60,049 new cases in one day due to the Omicron variant, with 250,000 new cases in a 7-day period.

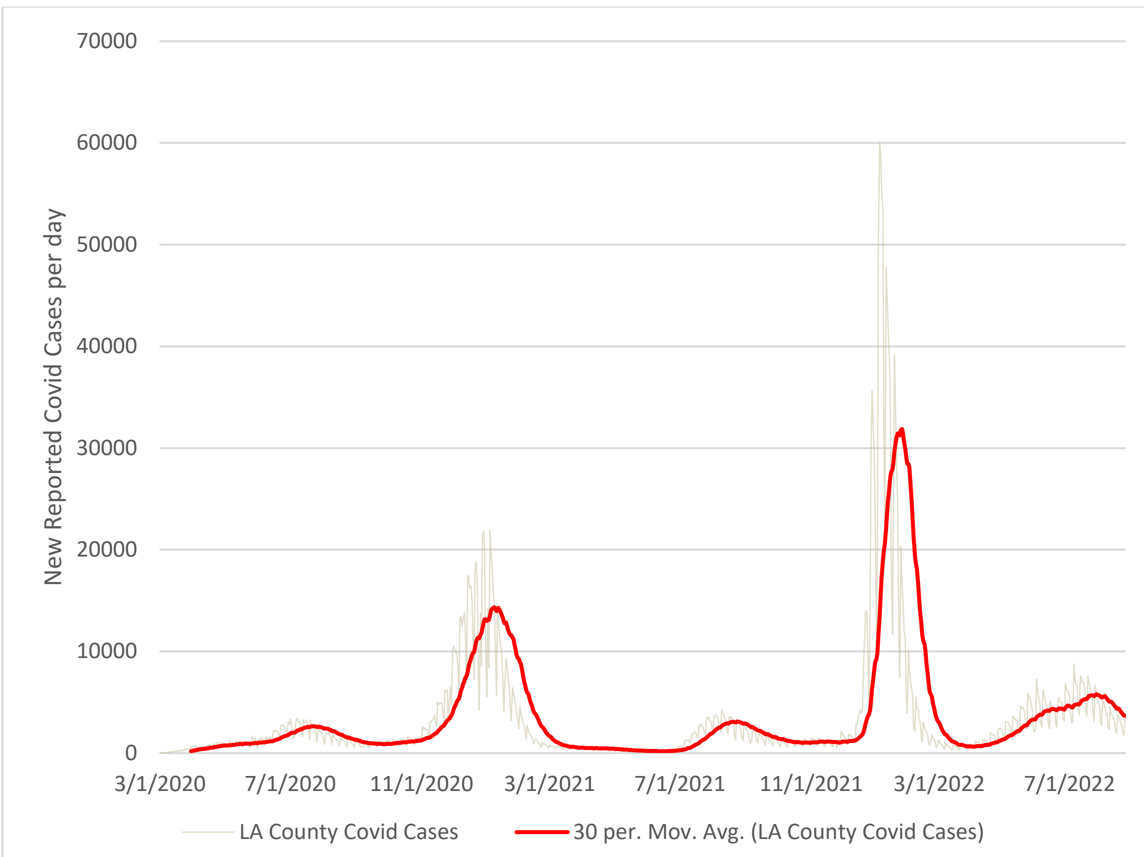


Figure 5. LA County Covid Cases data (provided by Los Angeles County Dept. of Public Health)

Covid Cases and Vessel Dwell Time

The figure below displays the 30-day moving average for vessel dwell time for ships at the Port of Long Beach and the 30-day moving average of new Covid cases in Los Angeles County. It can be seen that the average vessel dwell time was around 60 hours in March 2020. Shortly after the first surge in LA County Covid cases in June-July 2020, the vessel dwell time begins to increase sharply in August 2020. However, when the Covid cases begin to subside, in the fall of 2020, the vessel dwell time continues its climb up to 100 hours. From here on out, through the remainder of the study period, the average vessel dwell time hovers between 80 and 120 hours and appears unaffected by Covid surges in the county. It should be noted that the vessel dwell time was not affected by the major surge in cases at the beginning of 2022. According to the figure, a relationship is unlikely to exist between local Covid cases and vessel dwell time. The Pearson correlation coefficient of 0.2 indicates no correlation between local Covid cases and vessel dwell time at the Port of Long Beach.

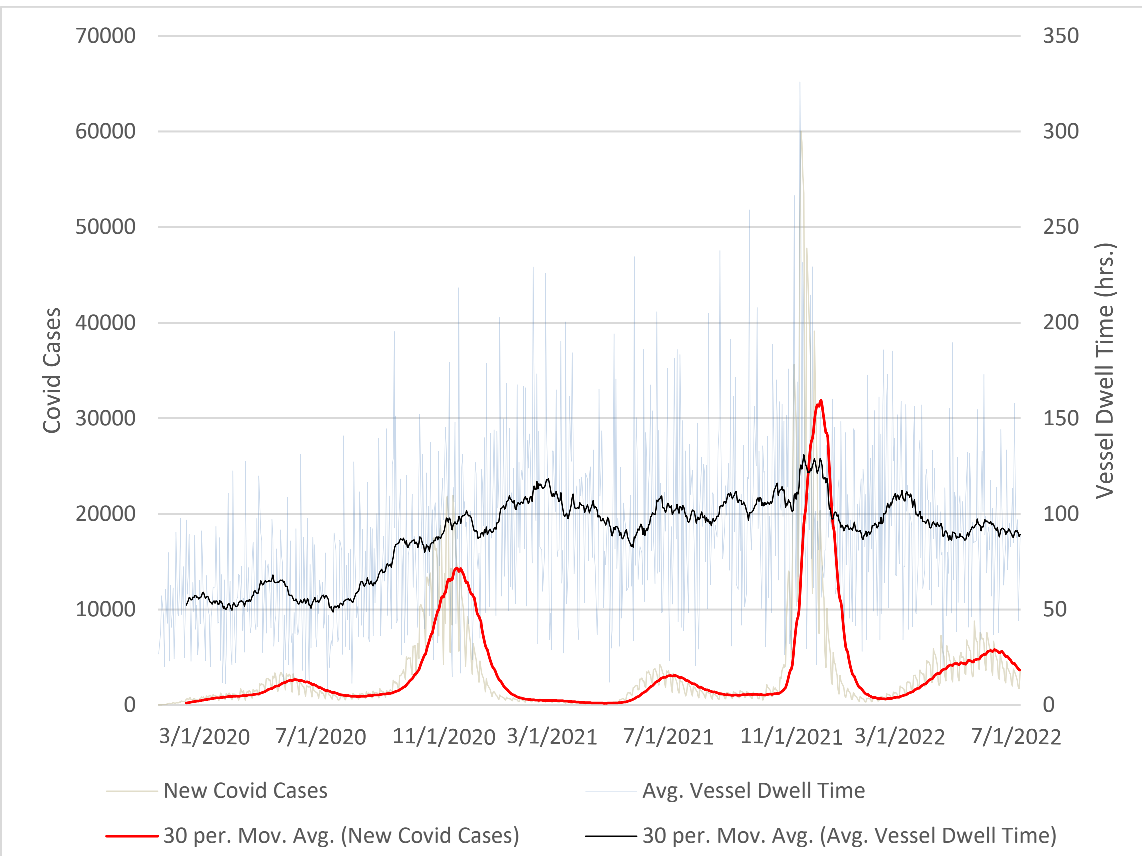


Figure 6. Port of Long Beach Vessel Dwell Time and LA County Covid Cases

Ship Arrivals/Departures and Vessel Dwell Time

The figure below displays the 30-day moving average for arrivals, departures and vessel dwell time at the Port of Long Beach. The 30-day average for arrivals and departures hovers around three ships per day until July of 2020 when it increases to four ships per day. Shortly after the peak of four ships per day, the 30-day average for arrivals and departures recedes back to three ships per day by October 2020 where it remains for the remainder of the study period. Vessel dwell time measures the time elapsed from the ships port entrance to port departure. The 30-day average dwell time begins around 60 hours from January 2019 until July 2020. In July 2020, immediately after the increase in ship arrivals/departures, the vessel dwell time begins to increase. The increase in ship arrivals may have overloaded the port and caused efficiency to suffer which is reflected in the elevated dwell times. From late 2020 through the remainder of the study period, the 30-day average dwell time fluctuates between 80 and 120 hours, with a peak of 130 hours in January 2022. According to the figure, the increase in ship arrivals/departures may have resulted in the initial increase in dwell times; however, the association concludes after the initial dwell time uptick in the summer of 2020. The Pearson correlation coefficient of -0.25 indicates a weak, negative correlation between ship arrivals and vessel dwell time at the Port of Long Beach.

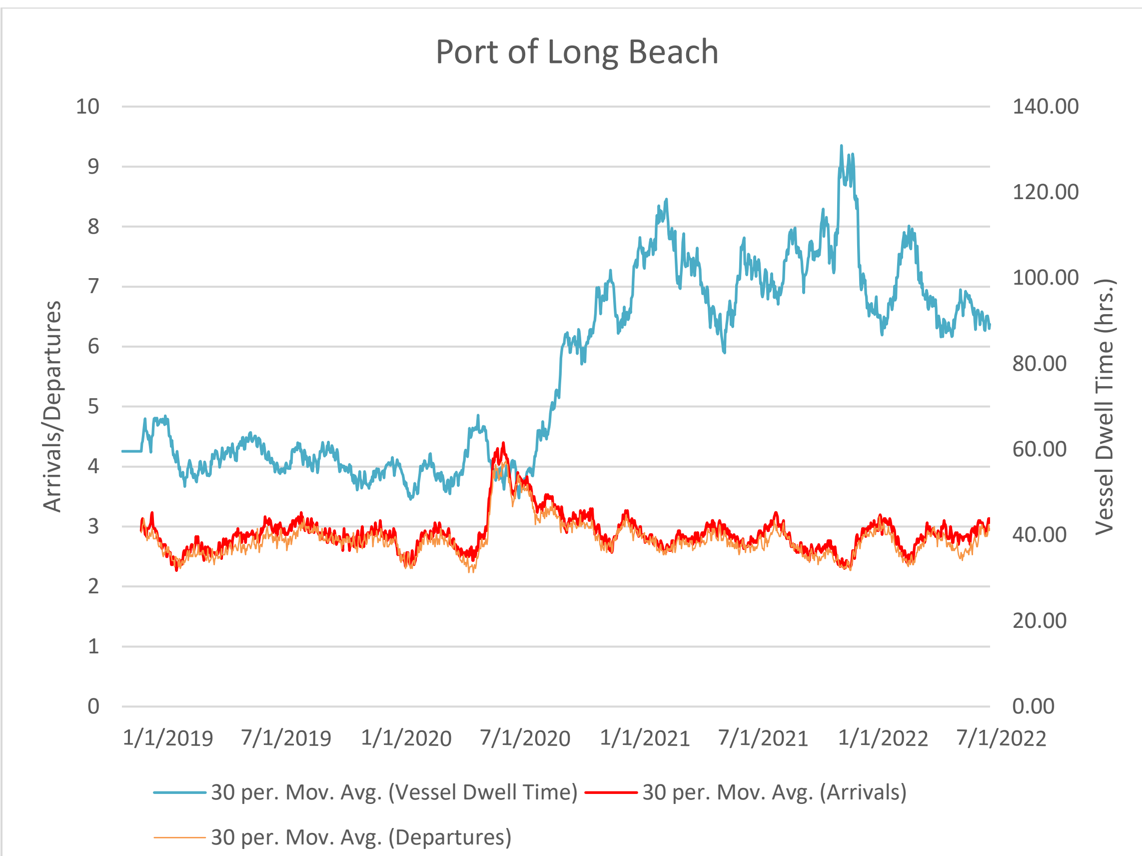


Figure 7. Port of Long Beach Arrivals, Departures, and Vessel Dwell Time

Container Throughput and Vessel Dwell Time

The figure below displays the monthly average dwell time and the monthly total container throughput in TEUs for the Port of Long Beach. The monthly throughput at the Port of Long Beach fluctuated between 600,000 and 700,000 TEU's between January 2019 and June 2020, with a slight dip between February 2020 and April 2020. When compared to 2019, there was a 12% reduction in container throughput at the port between January and June 2020. In July 2020, the monthly throughput at the port broke 700,000 TEU's and the throughput at the port fluctuated between 700,000 TEU's and 900,000 TEU's for the remainder of the study period. When compared to 2019, there was a 20% increase in container throughput at the port between July 2020 and August 2022.

The monthly average dwell time begins around 60 hours in January 2019 and remains steady throughout the year. The dwell times begin to tick down in early 2020. When compared to 2019, dwell times at the port decreased 12% between January and August 2020. This is likely due to the reduced throughput the port experienced during this period. In September, the dwell time begins to increase towards 100 hours in December of 2020. The dwell time from September 2020 through the remainder of the study period increased 37% when compared to 2019. The increase in dwell time is likely a result of the 20% increase in container throughput. A Pearson correlation coefficient of 0.80 indicates a strong, positive correlation between container throughput and vessel dwell time at the Port of Long Beach.

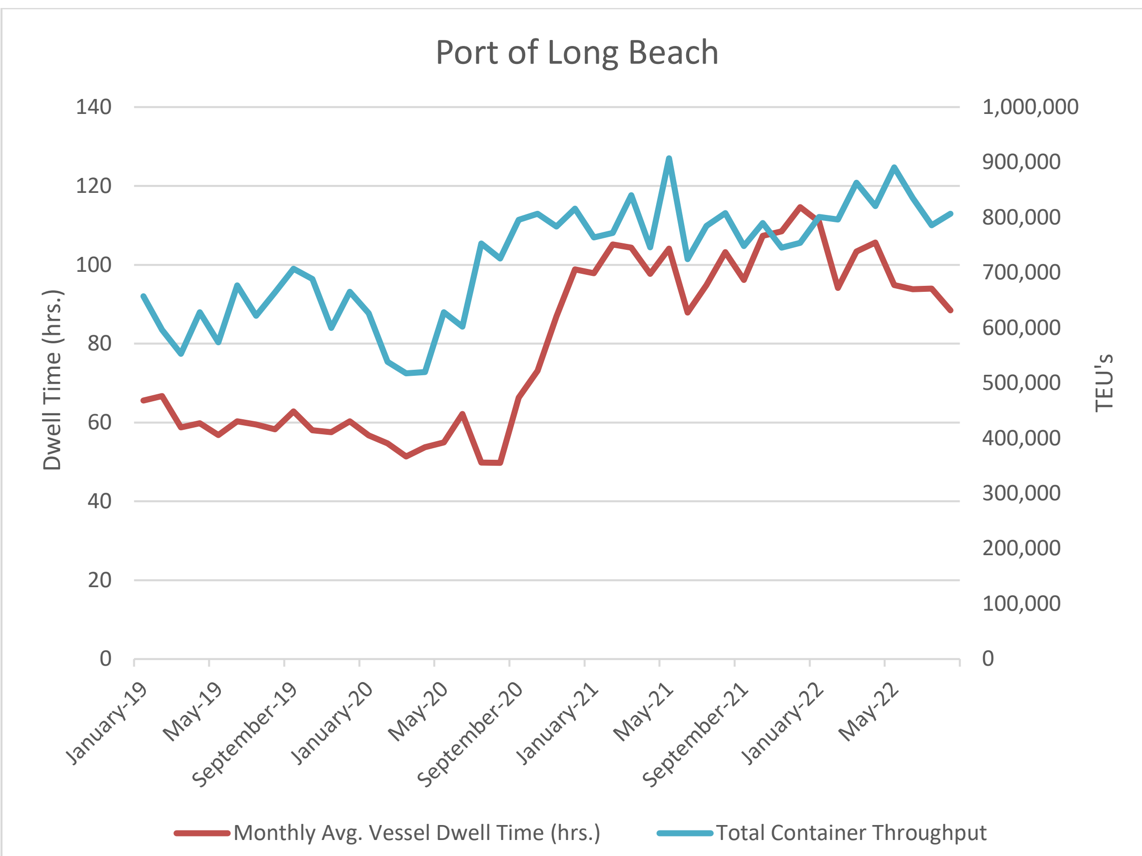


Figure 8. Port of Long Beach Dwell Time and Container Throughput

Port of New York and New Jersey

Covid Timeline

New York City is the most populous city in America with 8,335,897 people [77], and the most densely populated city in America. Additionally, the New York-Newark-Jersey City metropolitan area has a population of 19.77 million people [78]. The following is a summary of the Covid-19 related government orders as well as some key miles stones experienced in New York City, NY over course of the study period. Figure 13 illustrates 30-day moving average of new Covid-19 cases in New York City as well as 30-day moving average for vessel dwell time for ships at the Port of New Yortk and New Jersey, for reference.

- March 2, 2020: First Covid-19 case reported in New York City [79].
- March 12, 2020: State of emergency declared for the city, gatherings of 500 or more people barred [80]
- March 14, 2020: First Covid-19-related death reported in the city, public schools close down [80].
- March 15, 2020: Restaurants, bars, and cafes ordered to close and limited to takeout only [81]
- March 22, 2020: New York State On Pause executive order issued, all non-essential businesses close [81].
- March 31, 2020: New York City surpasses 1,000 Covid-19-related deaths [80].
- April 15, 2020: All people ordered to wear face coverings [80].
- June 8, 2020: Phase 1 reopening begins, allowing certain industries to reopen [83].
- June 22, 2020: Phase 2 reopening begins, including the resumption of professional services, retail, etc. [83].
- July 6, 2020: Phase 3 begins, allowing on-location restaurants without indoor dining to resume service [83].
- July 19, 2020: Phase 4 begins, allowing arts, entertainment, recreation, and education.
- September 29, 2020: Elementary students return to in-person learning [83].
- September 30, 2020: 25 percent occupancy allowed for indoor dining [83].
- November 13, 2020: New restrictions, including curfews on restaurants and gyms, and limiting gatherings in private homes to 10 people, go into effect [83].
- November 19, 2020: NYC elementary schools return to remote learning [83].
- December 7, 2020: NYC elementary schools return to the classroom [83].
- January 14, 2021: City reports peak of 7,725 new Covid-19 cases in one day [83].
- February 14, 2021: Vaccines become available to healthcare workers [83].
- February 15, 2021: Middle schools open in the city [83].
- March 22, 2021: High schools open in the city [83].
- March 30, 2021: New Yorkers aged 30 and up become eligible for vaccines [83].
- December 31, 2021: City reports 49,724 new cases in one day due to the Omicron variant [83].

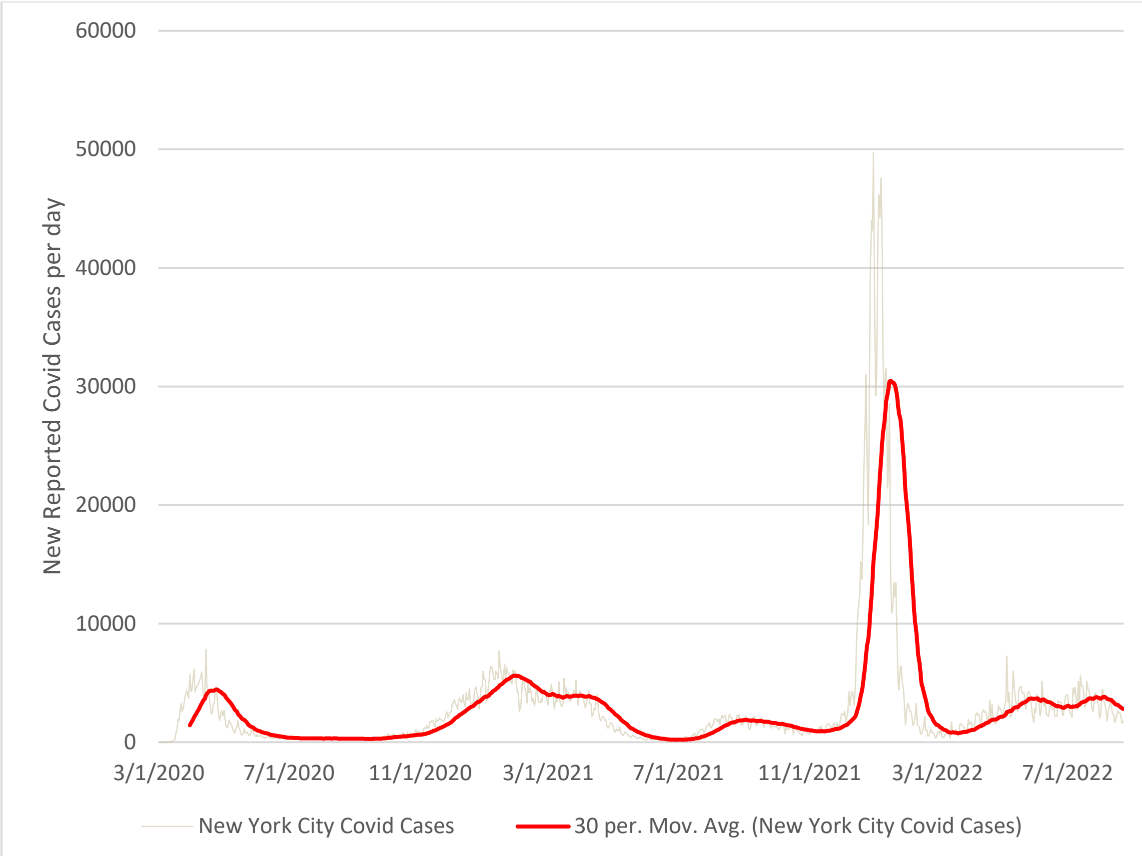


Figure 9. New York City Covid Cases (data provided by New York Dept. of Health)

Covid Cases and Vessel Dwell Time

The figure below displays the 30-day moving average for vessel dwell time for ships at the Port of New York and New Jersey and the 30-day moving average of new Covid cases in New York City. It can be seen that the average vessel dwell time is around 30 hours in March 2020. At this time, New York City is quickly beginning to see a rise in Covid cases in March and April 2020. As the surge in cases begins to decline around June and July 2020, the average vessel dwell time begins to increase. The vessel dwell time continues increasing in to 2021. By the time the second Covid surge happens, the vessel dwell time has peaked at 56 hours in January 2021, and it now hovers between 40 and 50 hours for the remainder of the study period. At this point, the vessel dwell time seems unaffected by the surge in Covid cases in New York City. As cases surge and decline, the vessel dwell time remains steady. It should be noted that the vessel dwell time was not affected by the major surge in cases at the beginning of 2022. According to the figure, there does not appear to be a relationship between local Covid cases and the vessel dwell time. The Pearson correlation coefficient of 0.2 indicates no correlation between local Covid cases and vessel dwell time at the Port of New York and New Jersey.

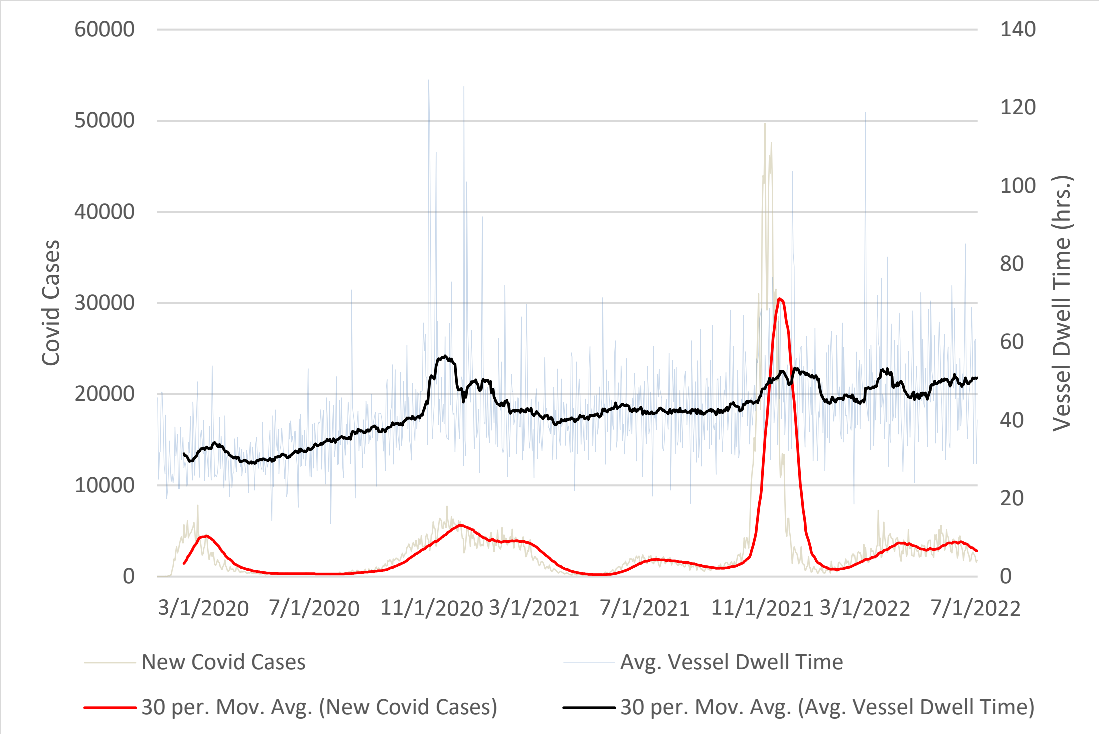


Figure 10. Port of New York and New Jersey Vessel Dwell Time and New York City Covid Cases

Ship Arrivals/Departures and Vessel Dwell Time

The figure below displays the 30-day moving average for arrivals, departures and vessel dwell time at the Port of New York and New Jersey. The 30-day average for arrivals and departures is around six ships per day for the entire study period. The 30-day average dwell time begins around 37 hours in January 2019. The dwell time varies between 30 and 40 hours until November 2020 when it breaks 40 hours and peaks at around 56 hours in January 2021. After the peak, the dwell time reduces to 40 hours by May 2020. For the remainder of the study period the vessel dwell time varies between 40 and 50 hours. According to the figure, there does not appear to be a relationship between ship arrivals/departures and the vessel dwell time. The Pearson correlation coefficient of 0.07 indicates a lack of any correlation between ship arrivals and vessel dwell time at the Port of New York and New Jersey

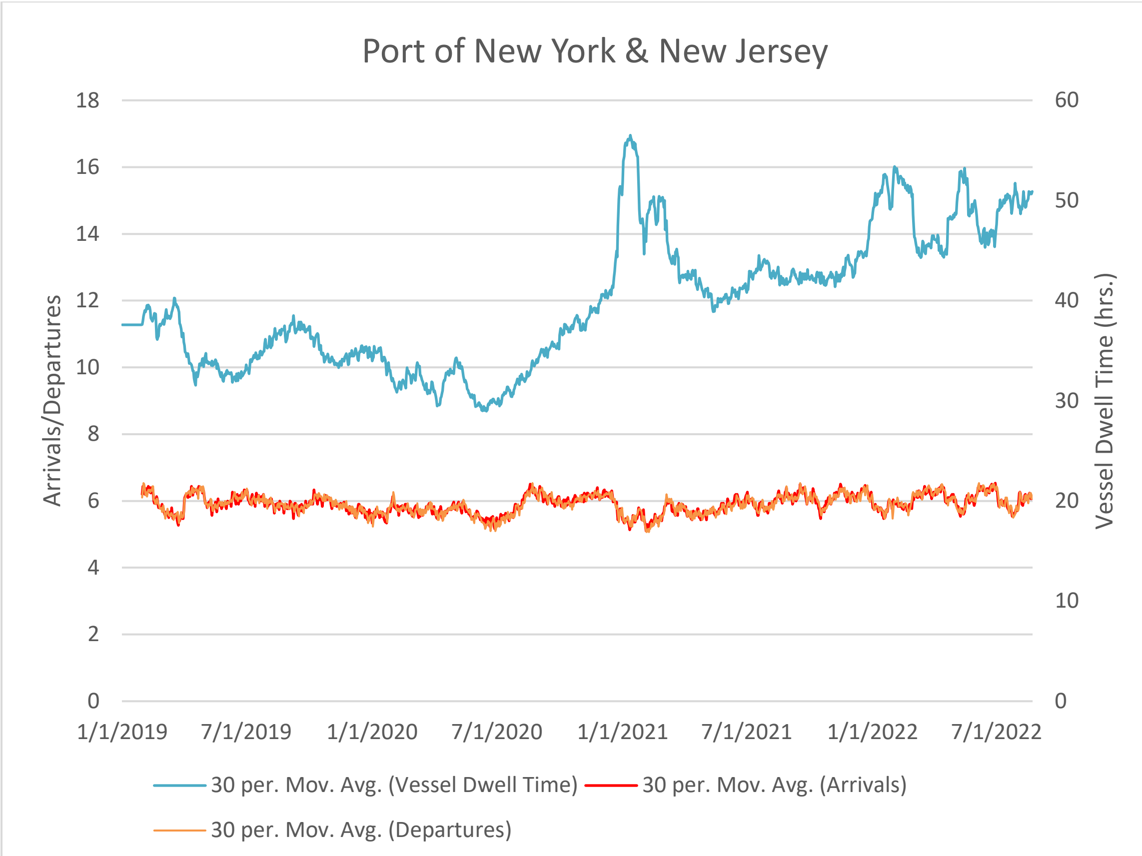


Figure 11. Port of New York and New Jersey Arrivals, Departures, and Vessel Dwell Time

Container Throughput and Vessel Dwell Time

The following figure displays the monthly average dwell time and the total container throughput in twenty-foot equivalent units (TEU's) for the Port of New York and New Jersey. The monthly throughput at the Port of New York and New Jersey fluctuated between 500,000 and 700,000 TEU's between January 2019 and August 2020. When compared to 2019, the container throughput at the port was reduced by 10% between January and July 2020. Beginning in August 2020, the throughput rebounded dramatically at the port. With February 2021 being the only exception, the monthly throughput fluctuated between 700,000 and 869,000 TEU's for the remainder of the study period. This represents a 21% increase when compared to 2019.

The monthly average dwell time begins around 35 hours from January 2019 and remains steady throughout the year. At the beginning of 2020, the dwell time dropped by 10% during the months of January to July 2020 when compared to 2019. In September 2020, the dwell time began to increase up to around 45 hours in December 2020. From there on, the monthly average dwell time varies between 42 hours and 51 hours for the remainder of the study period. From September 2020 through the remainder of the study period, the vessel dwell time was 18% higher. The Pearson correlation coefficient of 0.80 indicates a strong, positive correlation between container throughput and vessel dwell time at the Port of New York and New Jersey.

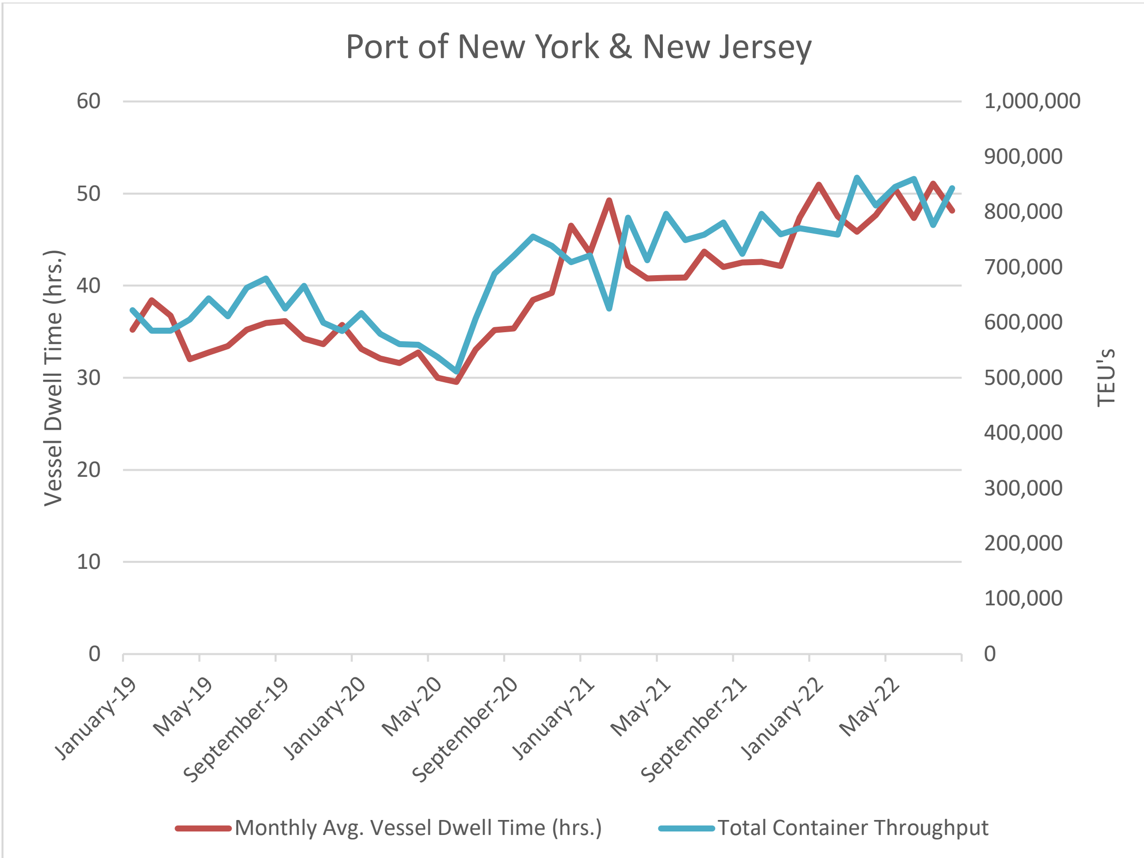


Figure 12. Port of New York and New Jersey Dwell Time and Container Throughput

Port of Rotterdam

Covid Timeline

Rotterdam is the second largest city in the Netherlands with a population of 655,000 [84]. The city is home to the largest port in Europe. The following is a summary of the Covid-19 related government orders as well as some key miles stones experienced in Rotterdam, Netherlands over course of the study period. Figure 17 illustrates 30-day moving average of new Covid-19 cases in Rotterdam as well as 30-day moving average for vessel dwell time for ships at the Port of Rotterdam, for reference.

- January 24, 2020: COVID-19 first emerges in Europe [85].
- February 27, 2020: Rotterdam reports its first confirmed case of COVID-19 from a patient who traveled from northern Italy [86].
- March 6, 2020: Rotterdam records the first death in the Netherlands due to COVID-19] [87].
- March 9, 2020: Prime Minister Rutte advises people in Noord-Brabant to work from home and bans handshaking [86].
- March 12, 2020: Work from home order extended to the entire country, and gatherings of more than 100 people are banned [86].
- March 15, 2020: Dutch PM announces an 'intelligent lockdown,' closing bars, restaurants, schools, gyms, and nursing home visitations are not allowed. People are urged to stay

home, but can move around freely if maintaining a 1.5-meter distance from others. Offenders are fined €390 [88].

- March 23, 2020: Stricter lockdown rules are announced, closing 'contact professions,' banning groups of more than three people in public, extending the ban on large gatherings until June 1, and imposing fines for non-compliance [86].
- March 31, 2020: The lockdown is extended until April 28, with the number of deaths at 1,039 [86].
- May 11, 2020: Primary schools reopen, and children under 12 are allowed to play sports and train with clubs. Ban on public events extended to September 1 [86].
- June 1, 2020: Restaurants, pubs, theaters, and museums reopen for a maximum of 30 visitors [86].
- July 1, 2020: Restrictions further relaxed, allowing events, no maximum number of people at transit stations, and no maximum gathering restrictions [86].
- August 2020: Number of cases begin to rise, and measures are introduced to restrict gatherings to six people.
- September 29, 2020: Gatherings limited to three people, restaurants and bars must close early, and no spectators allowed at sports events.
- January 2022: Rotterdam sees a surge in new Covid-19 cases, with a peak of 3,600 new cases reported on February 9, 2022 [89]. Despite this, on January 14, 2022, the last of the Covid lockdowns in the Netherlands once.
- January 14, 2022: Last of the Covid-19 lockdowns in the Netherlands relax their restrictions for the final time [86].

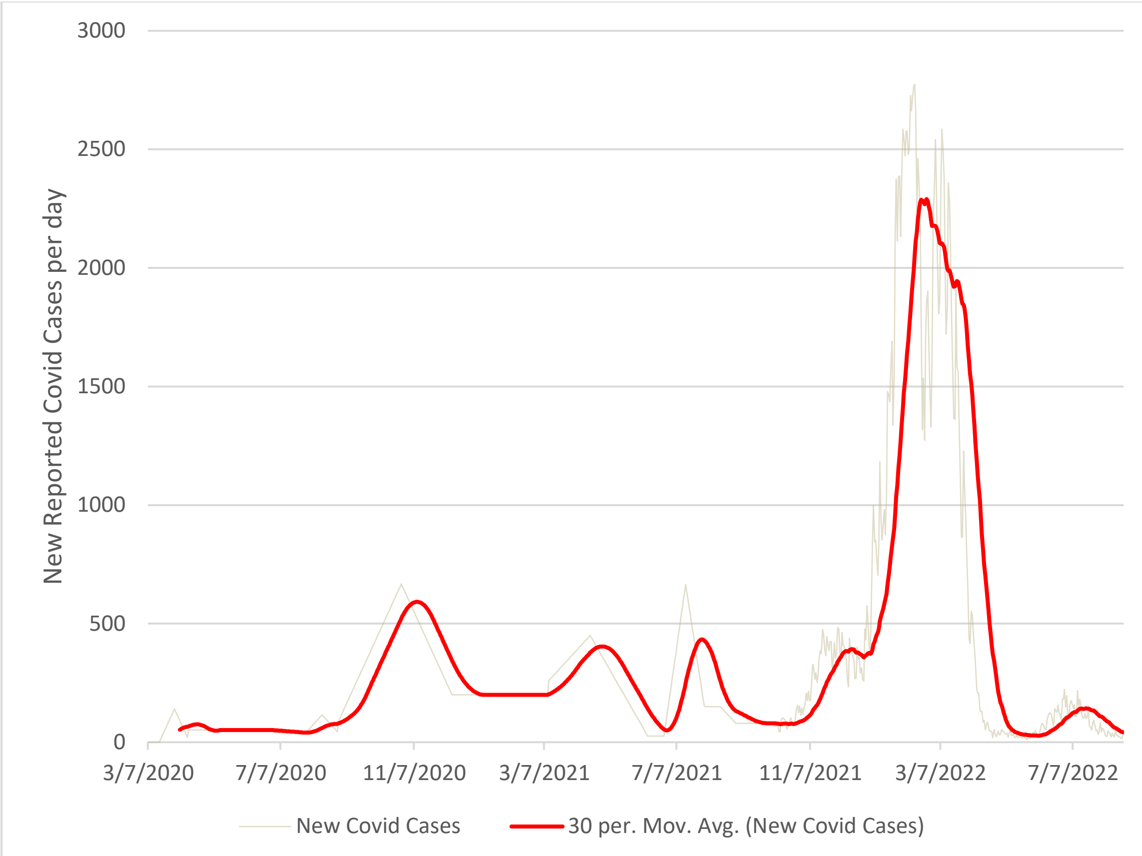


Figure 13. Rotterdam Covid Cases (Figure provided by the Dutch National Institute for Public Health and the Environment)

Covid Cases and Vessel Dwell Time

The figure below displays the 30-day moving average for vessel dwell time for ships at the Port of Rotterdam and the 30-day moving average of new Covid cases in Rotterdam. It can be seen that the vessel dwell time does fluctuate between 10 and 20 hours, and that there is a large Covid surge in the spring of 2022; however, the vessel dwell time begins to decrease back down to 10 hours as the Covid cases in the city decrease around April and May 2022. According to the figure, a relationship is unlikely to exist between local Covid cases and vessel dwell time. The Pearson correlation coefficient of 0.03 indicates no correlation between local Covid cases and vessel dwell time at the Port of Rotterdam.

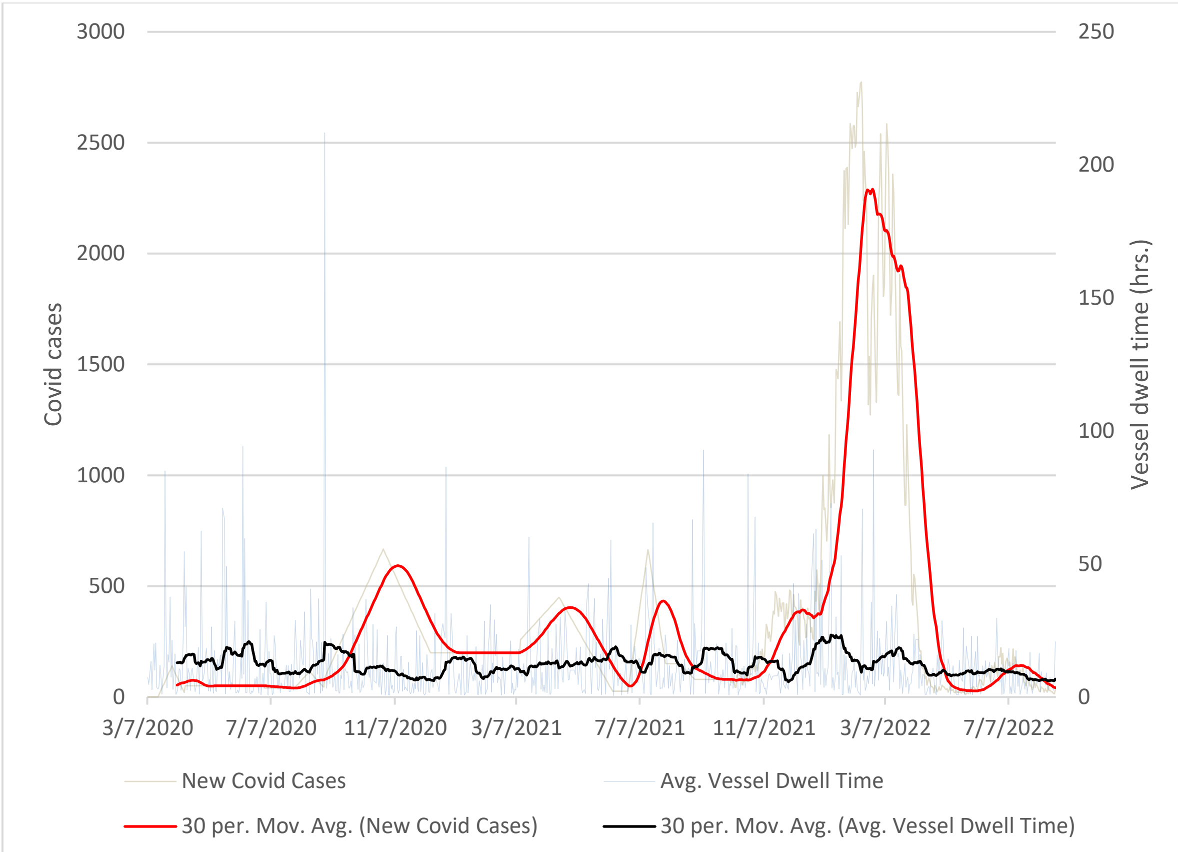


Figure 14. Port of Rotterdam Vessel Dwell Time and Rotterdam Covid Cases

Ship Arrivals/Departures and Vessel Dwell Time

The figure below displays the 30-day moving average for arrivals, departures and vessel dwell time at the Port of Rotterdam. The 30-day average for arrivals and departures fluctuates between 3 and 4 ships from January 2019 to October 2020. In October 2020, the 30-day average briefly increases to over 4 ships per day. After this peak, the average slowly descends back to 3 ships per day around April 2021. The 30-day average for arrivals and departures remains steady for the remainder of the study period before experiencing a sharp increase in August 2022. The 30-day average dwell time begins around 10 hours in January 2019. The average dwell time at the Port of Rotterdam fluctuates greatly throughout the study period; the dwell time swings between 10 and 20 hours for the study period. The maximum dwell time is 23 hours in April 2019, and the minimum average dwell time is 6 hours in November of 2019. According to the figure, there does not appear to be a relationship between ship arrivals/departures and the vessel dwell time. Additionally, a Pearson correlation coefficient of 0.18 indicates a lack of correlation between ship arrivals and vessel dwell time at the Port of Rotterdam.

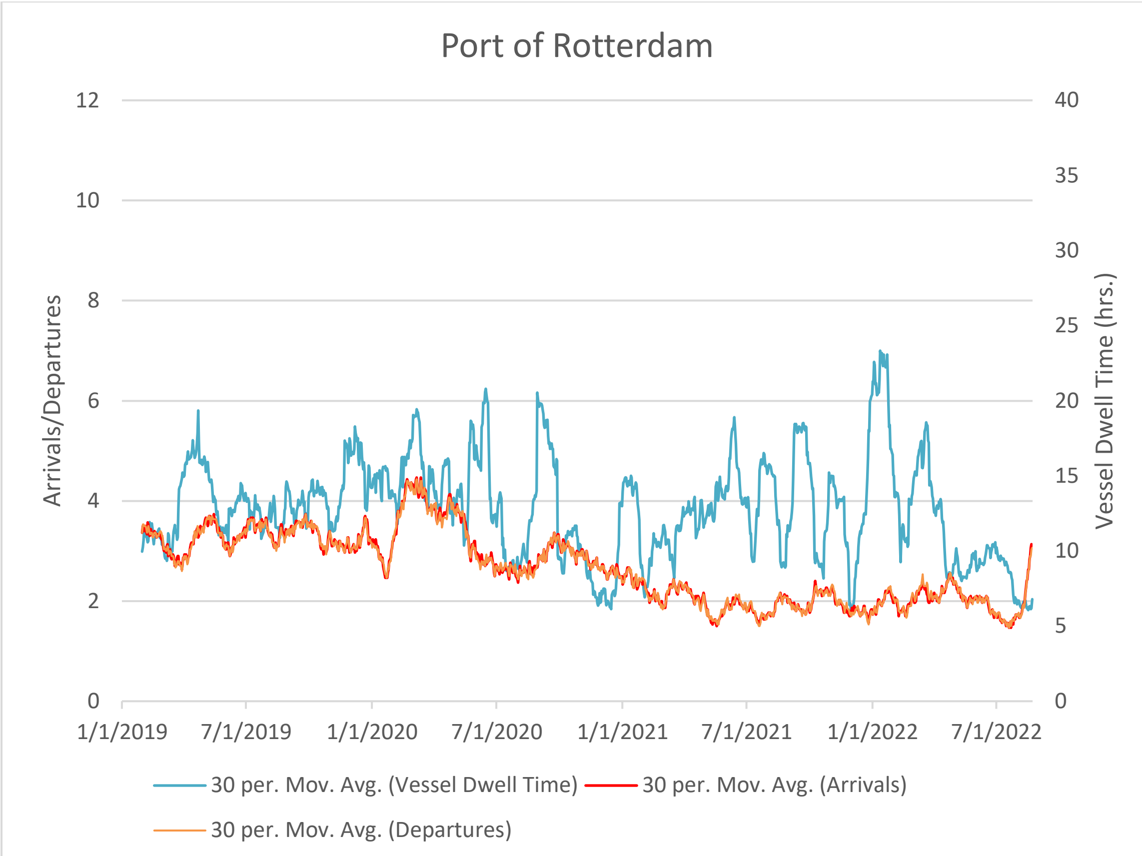
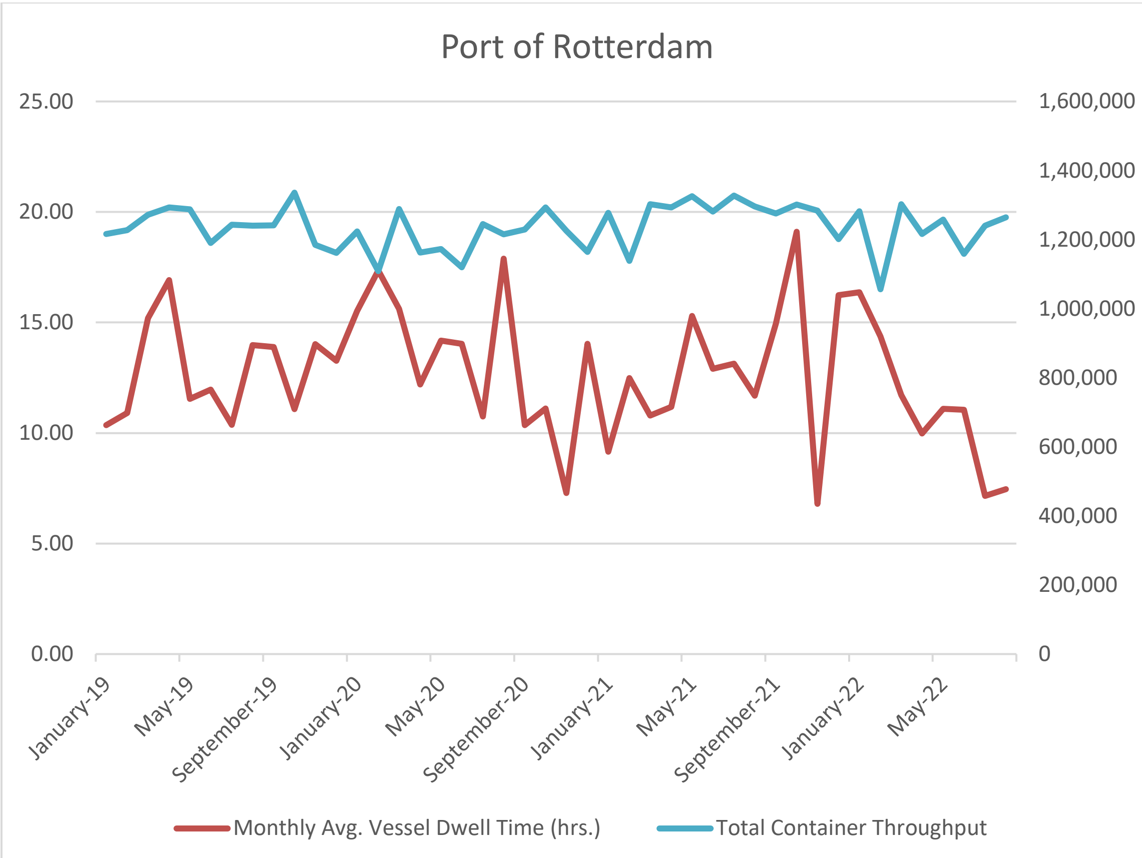


Figure 15. Port of Rotterdam Arrivals, Departures, and Vessel Dwell Time

Container Throughput and Vessel Dwell Time

The following figure displays the monthly average dwell time and the total container throughput in twenty-foot equivalent units (TEU's) for the Port of Rotterdam. The monthly throughput at the Port of Rotterdam fluctuated between 1,056,211 and 1,335,972 TEU's for the duration of the study period. The lowest volume of throughput occurred in February 2022, and the highest volume of throughput occurred in October 2019. When compared to 2019, the throughput at the port was similar for the entire study period; i.e. there was not a large influx of goods when compared to past years.

The monthly average dwell time begins around 10 hours in January 2019 and averaged 13 hours that year. From January to July 2020, the dwell time was 8% higher than the 2019 average; however, the average dwell time was 14% lower for the remainder of the study period. The lowest average monthly dwell time is 6.8 hours in November 2021, and the highest average monthly dwell time is 19 hours in October 2021. The Pearson correlation coefficient of -0.13 indicates a lack of correlation between container throughput and vessel dwell time at the Port of Rotterdam.



Container throughput data provided by the Port of Rotterdam

Figure 16. Port of Rotterdam Dwell Time and Container Throughput

Port of Shanghai

Covid Timeline

Shanghai, which is the largest and wealthiest city in China, has a population of almost 27 million people. The metropolitan area around Shanghai has a population of nearly 30 million and is the third largest in the world behind Tokyo and Delhi [90]. The following is a summary of the Covid-19 related government orders as well as some key miles stones experienced in Shanghai, PRC over course of the study period.

- January 20, 2020: First case of coronavirus reported in Shanghai [91].
- January 2020: Initiatives taken at the border and in the city, including negative test certificates, quarantine for inbound travelers, home quarantine, and fuse measures for international flights.
- January 2020: Local initiatives began, such as symptom-based and occupation-based screening, contact tracing, social distancing, and facemask requirements.
- March 2, 2020: Partial closure of public places in Shanghai.
- March 12, 2020: Closure of kindergartens, primary, secondary, and vocational schools; universities closed on March 15.

- March 2020: Implementation of grid management for high-risk and non-high-risk areas in Shanghai.
- March 16-17, 2020: Lockdown of high-risk areas and massive PCR screenings.
- March 18-20, 2020: Mass PCR screenings for non-high-risk areas.
- March 21, 2020: Inbound flights being diverted to combat the spread.
- March 28, 2020: Eastern Shanghai enters a full lockdown until May 31.
- April 1, 2020: Western Shanghai follows suit with a full lockdown.
- June 1, 2020: Complete lockdowns in Shanghai lifted [92] .

Several sources were found that reported Covid cases in Shanghai. These sources seem unreliable and show conflicting data. The figure below, provided by the Johns Hopkins University Center for Systems Science and Engineering (CSSE), displays the number of Covid cases. However, it seems unlikely that the most active Covid cases in a city of 27 million was 31,510. It should be noted that the raw data could not be found for Shanghai covid cases. One source from April 2022, states that Shanghai only reported 285 Covid related deaths, from around 500,000 confirmed cases of Covid [94]. The same Reuters article states, “Several studies have cast doubt on China's numbers, with one released in June 2020 saying they fall outside of recognised and accepted medical norms. It estimated that 36,000 people could have died in Wuhan alone, more than 10 times the official figure.”

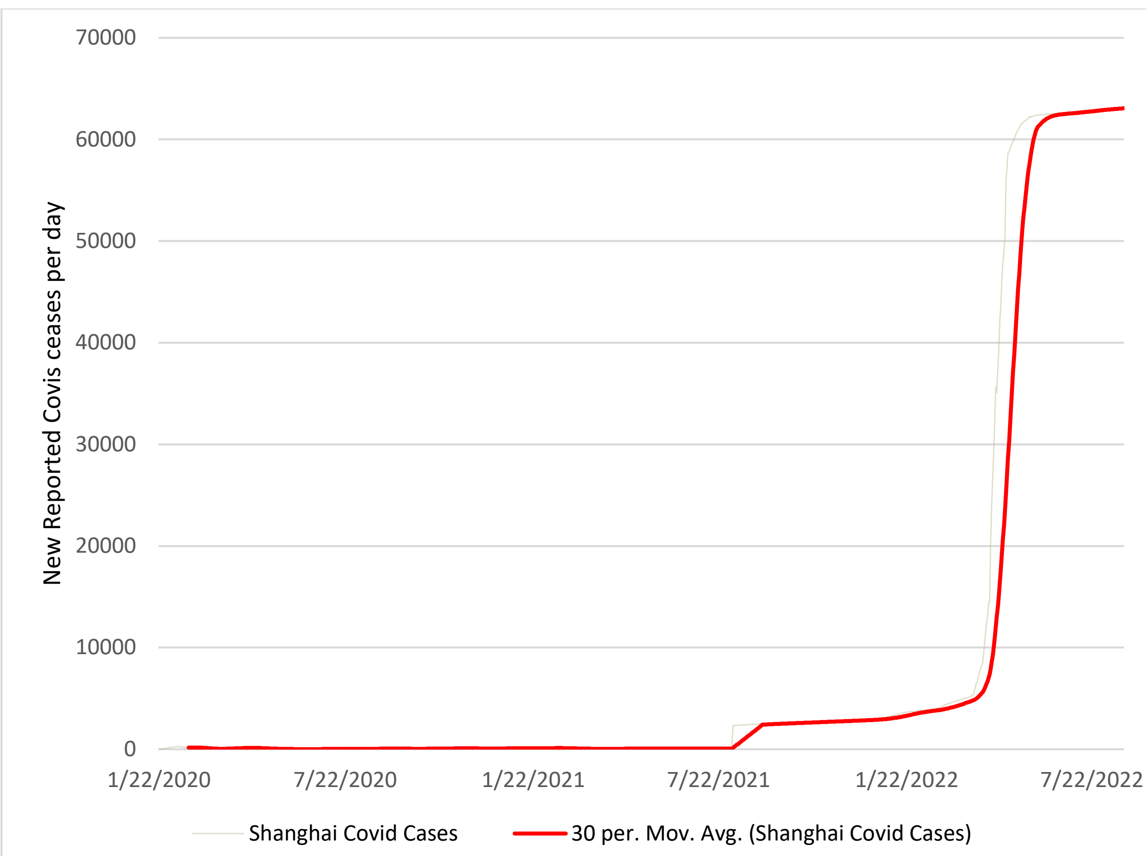


Figure 17. Shanghai Covid Cases (provided by the Johns Hopkins University CSSE)

Covid Cases and Vessel Dwell Time

The figure that displays the 30-day moving average for vessel dwell time for ships at the Port of Shanghai and the 30-day moving average of new Covid cases in Shanghai was omitted due to the unreliability of the Covid case data.

Ship Arrivals/Departures and Vessel Dwell Time

The figure below displays the 30-day moving average for arrivals, departures and vessel dwell time at the Port of Shanghai. The 30-day average for arrivals and departures fluctuates between 37 and 45 ships from January 2019 through August 2019. In September 2019, the 30-day average number of ships increased sharply up to 54 ships per day before returning to the previous average of 42-45 ships per day. In January 2020, the 30-day average number of ships began to decrease. It dropped below 40 in early February 2020 and bottomed out at 35 ships per day by mid-February. The average remained below 40 ships per day until mid-March 2020. The average then hovered around the low 40's for the remaining study period, with dips below 40 in August through October 2021 and once again from April through June 2022. The 30-day average dwell time begins around 16 hours in January 2019. The average dwell time at the Port of Shanghai is consistently between 16 and 18 hours from January 2019 to September 2019. In September 2019, it dips all the way down to 13 hours before returning to previous levels by late October. The average dwell time remains consistent until late April 2020 when it dips below 15 hours once again. The average then begins increasing in August 2020 and climbs up to 17 hours. The 30-day average dwell time then remains between 17 and 19 hours for the remainder of the study period. Additionally, a Pearson correlation coefficient of -0.63 indicates a moderate, negative correlation between ship arrivals and vessel dwell time at the Port of Shanghai.

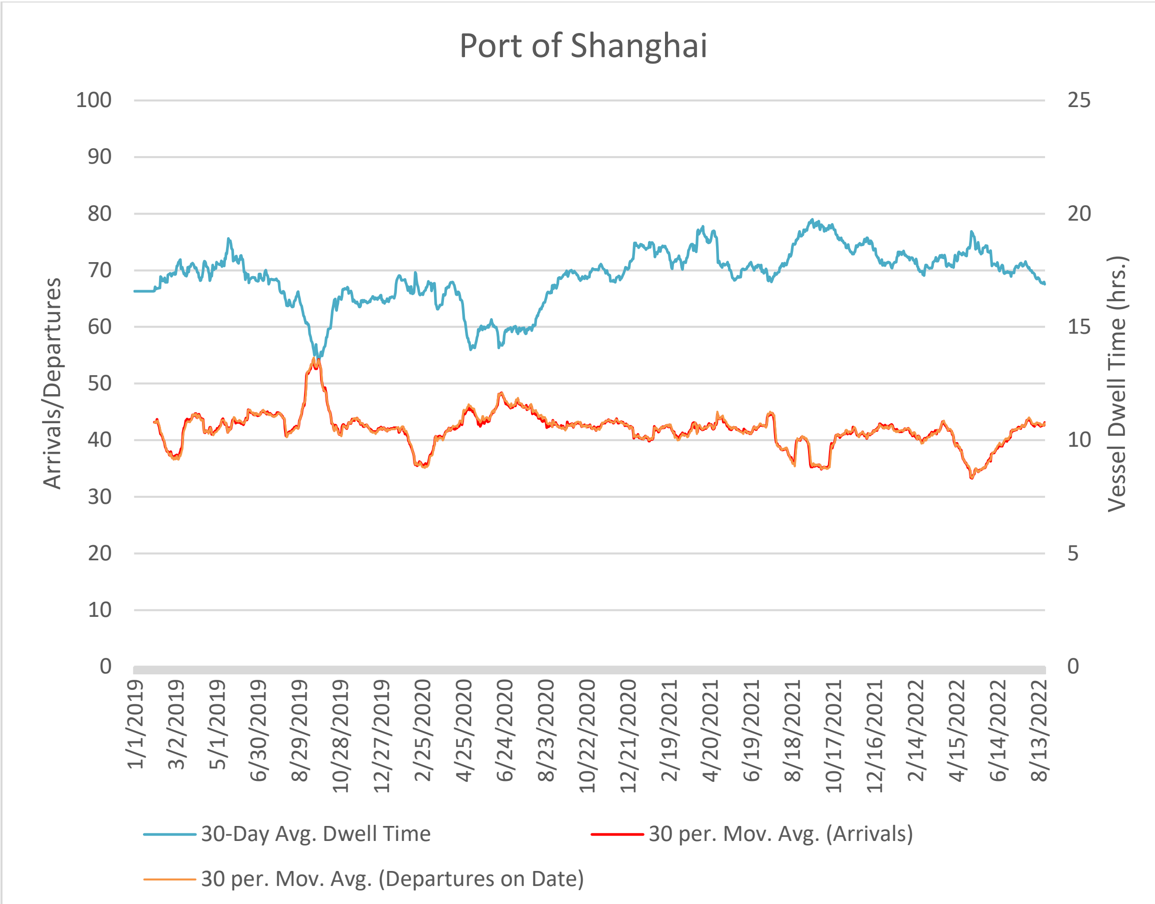


Figure 18. Port of Shanghai Arrivals, Departures, and Vessel Dwell Time

Container Throughput and Vessel Dwell Time

The following figure displays the monthly average dwell time and the total container throughput in twenty-foot equivalent units (TEU's) for the Port of Shanghai. The monthly throughput at the Port of Shanghai began at 3.75 million TEU's in January 2019, dropped to 2.85 million TEU's in February 2019 and then fluctuated between 3.6 and 3.8 million TEU's from March 2019 to January 2020. In February 2020, the total throughput dropped to its lowest level of the study period, 2.29 million TEU's. Afterwards the total container throughput returned to normal levels at the port. In October 2020, the port saw its second highest throughput of the study period with 4.2 million TEU's. For the remainder of the study period the throughput fluctuated between 3.0 and 4.3 million TEU's. The busiest months were August 2021 and January 2022, both with 4.3 million TEU's of throughput. From January to June 2020, the container throughput at the Port of Shanghai was reduced by 12% when compared to 2019; however it quickly recovered and averaged 7% more throughput for the remainder of the study period.

The monthly average dwell time for the Port of Shanghai is consistent throughout the study period. For the most part it fluctuated between 16 and 18 hours. In September 2019, the average monthly dwell time was at its lowest at 13.4 hours, and between April 2020 and July

2020, the average was between 14 and 15 hours. The highest monthly average dwell time was 19.3 hours in September 2021. From January to June 2020, the dwell time at the Port of Shanghai was reduced by 7% when compared to 2019. From July 2020 to the end of the study period the dwell time was up by 6% when compared to 2019. The Pearson correlation coefficient of 0.30 indicates a weak, positive correlation between container throughput and vessel dwell time at the Port of Shanghai.

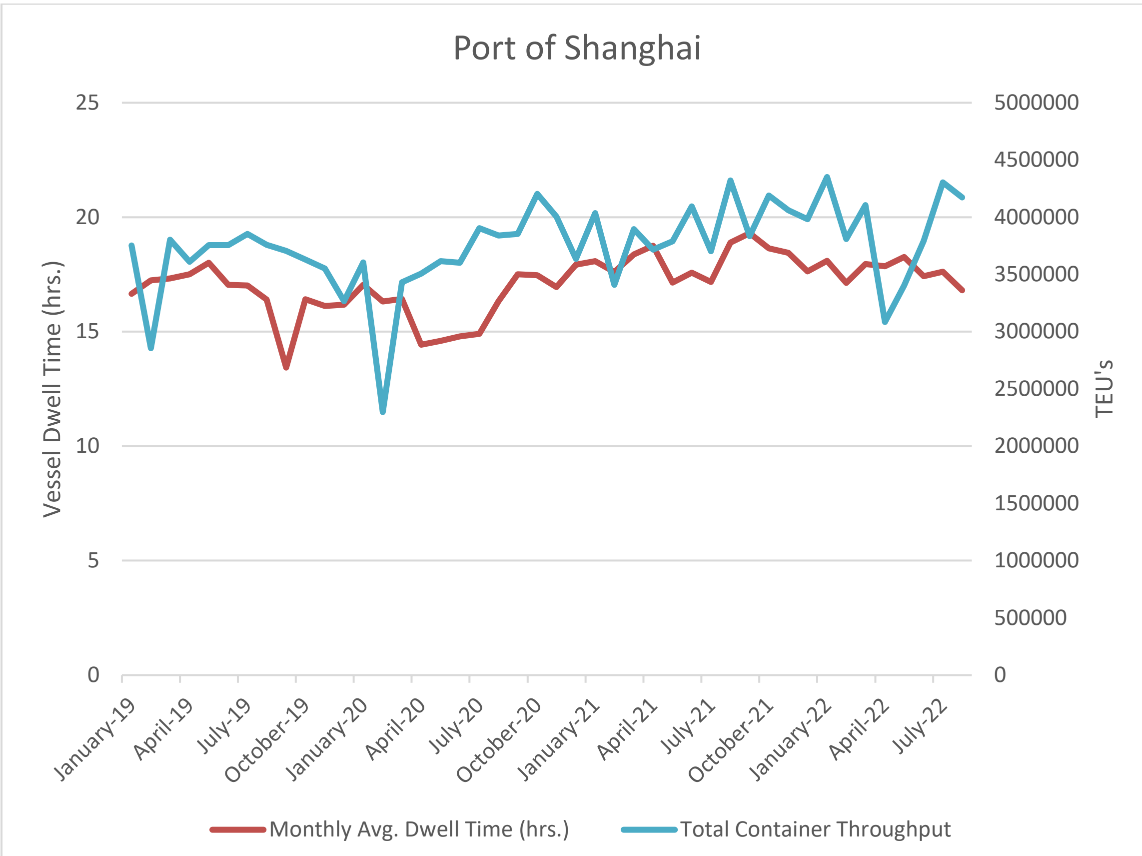


Figure 19. Port of Shanghai Dwell Time and Container Throughput

6. Discussion

Port of Long Beach

The Port of Long Beach was reported to be one of the most congested ports in the United States, as well as one of the main supply chain bottlenecks. There are many possible explanations for the congestion at the port; worker shortages due to sickness and lockdowns, trouble in the trucking industry that reduced the number of containers leaving the port, an increased volume of container ships, or an increased volume of containers being shipped.

Figure 10 displays the 30-day moving average for vessel dwell time of ships at the Port of Long Beach and the 30-day moving average of new Covid cases in Los Angeles County. The vessel dwell time at the port remained steady through the initial Covid wave in the spring of

2020. The first surge of viral infections came in the summer of 2020 when daily infections for the months of June through August rose by nearly 200% compared to March through May. In this same time period, the vessel dwell time rose by only 4.6%. From September through December, the Covid case average rose by 154% and the 30-day average vessel dwell time rose by 44% compared to the previous 3 months. In January 2021, the Covid cases peaked and began to subside over the next several months. The average new cases per day decreased by 57% but the vessel dwell time continued to increase by 23% from January through June 2021 when compared to the previous 4 months. From July 2021 through December 2021, daily Covid cases rose by 39% and the vessel dwell time rose by 3.5%. For the remainder of the study period, January through August 22, 2022, the daily average of Covid cases rose by 122% and the vessel dwell time decreased by 5%. These observations indicate that there is likely no relationship between local Covid cases and vessel dwell time; i.e. surges in viral infection did not affect port congestion. Additionally, the Pearson correlation coefficient of 0.2, indicates that there is no correlation between local Covid cases and vessel dwell time at the Port of Long Beach

Figure 11 displays the ship arrivals, departures, and vessel dwell time. It can be seen in the graph that the vessel dwell time, as well as the average amount of ships arriving and departing, remains steady from January 2019 until the summer of 2020. In the summer of 2020, there is a 33% increase in the 30-day average of ship arrivals/departures. This growth seems to cause a 60% increase in the vessel dwell time by the end of 2020. After the increase in ship arrivals and departures, the 30-day average drops back down to normal levels by January 2021; however, the vessel dwell time continues to increase and ends up 100% higher than previous levels by January 2021. The dwell time never recovers and stays elevated throughout the remainder of the study period. This observation leads to the conclusion that the 33% increase in ships may have overwhelmed the port, the vessel dwell times rose by 100% and the port was unable to recover and turn ships around as quickly as before. Though the increased ship arrivals in summer 2020 seem to cause the vessel dwell time to increase, there is nothing present that indicates the two are directly related. Additionally, the Pearson correlation coefficient of -0.25 indicates a weak, negative correlation between ship arrivals and vessel dwell time at the Port of Long Beach.

After further investigation into the volume of ship arrivals, the picture became clearer about what was actually happening at the port. While Figure 11 indicates a 33% increase in ship arrivals in the summer of 2020, it does not capture the backlog of container ships that were waiting to enter the port. In the data set, the timestamp of ships arriving at the port are not captured until the ship enters the port. However, due to the elevated vessel dwell times, container ships were anchoring anywhere from 25 to 150 miles away from the port and waiting their turn to dock and unload. Figure 24 below displays the amount of container ships waiting to dock at the Port of Los Angeles and Port of Long Beach. It can be seen that the number of ships waiting to dock begins to increase around October 2020; this is shortly after the spike in ship arrivals and the accompanying elevated vessel dwell times. It appears that the port became overloaded in the summer of 2020, the vessel dwell times began to increase shortly afterwards, and this led to ships being forced to anchor offshore and wait their turn to enter port. While it is unknown how many of the ships awaiting berth offshore were going to the Port of Long Beach, it does indicate that there was an elevated volume of ships sailing to the port that is not reflected in the data set. It also helps explain why the vessel dwell time never reduced to the previous times; the port was overloaded by an increased number of ship sailings.

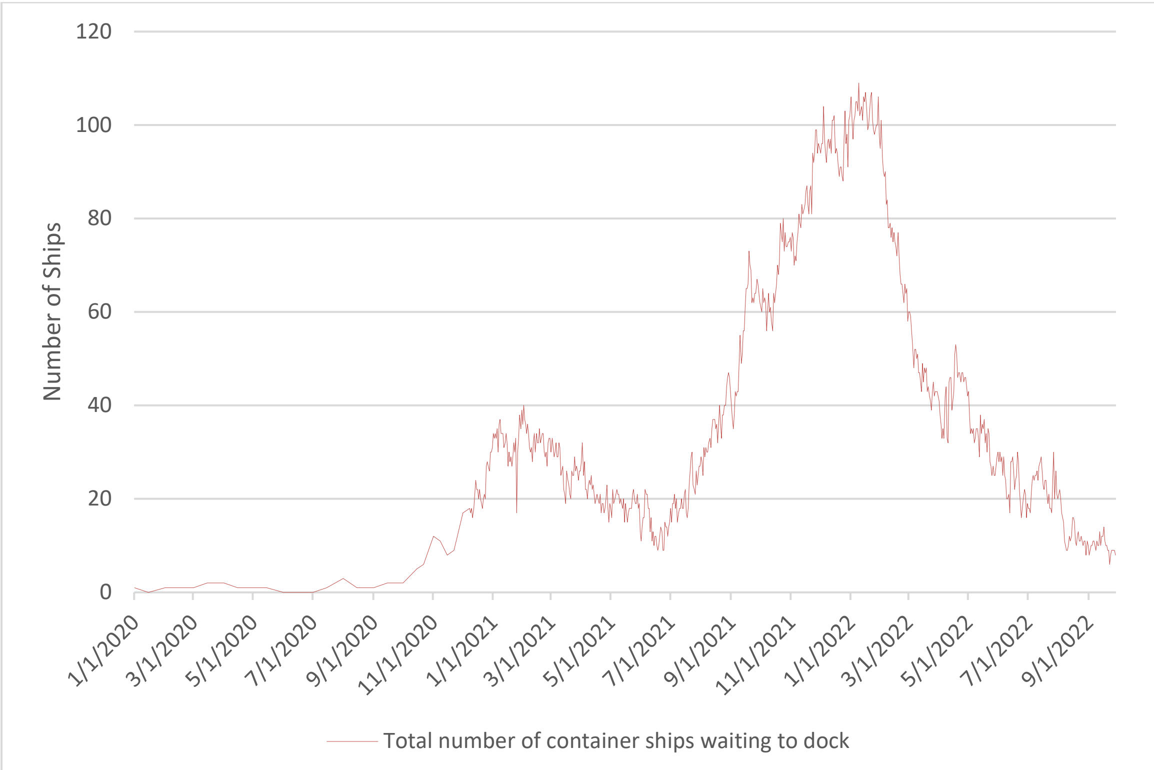


Figure 20. Port of Los Angeles and Long Beach Backlog (Chart: Dylan Miettinen Source: Marine Exchange of Southern California)

In 2019, the monthly average volume of container throughput was 636,000 TEU's per month. During this period, the highest monthly volume of throughput was 706,955 TEU's in September 2019 and the lowest was 552,821 TEU's in March 2019. When compared to 2019, the container throughput was reduced by 18% in February, 23% in March, and 22% in April. Overall, there was a 12% reduction in container throughput at the port between January and June 2020. This low volume of throughput can be attributed to the massive lockdowns throughout the United States as well as other countries. In the U.S. people were adjusting to a new lifestyle. People were working from home, restaurants and many other businesses were closed, and recreation and entertainment options were drastically altered. The pandemic severely altered the spending patterns of the consumer in the U.S. There was a shift away from services and a surge in spending on durable goods. Many of the durable goods being purchased are manufactured in Asia; therefore, they must be shipped to the consumers in the U.S. Looking at Figure 12, by July of 2020, the increased spending on retail goods is beginning to be reflected in the container throughput at the port. From July 2020 through the remainder of the study period, the monthly average volume of container throughput was 794,816 TEU's. This equates to a 20% increase in container throughput at the port between July 2020 and August 2022, compared to 2019. In this same period, the highest monthly throughput was 907,216 TEU's, or 30% higher than 2019 and the lowest monthly throughput was 724,297 TEU's, or 12% higher than 2019. According to reports, 2021 was the busiest year ever recorded at the port [95].

In Figure 12 it can also be seen that the increased container throughput coincided with the increase in monthly average vessel dwell time. In 2019, the monthly average vessel dwell time was 60 hours. When compared to 2019, dwell times at the port decreased 12% between January and August 2020. This is due to the reduced throughput the port experienced during this period. In September, the dwell time begins to increase towards 100 hours in December of 2020. The dwell time from September 2020 through the remainder of the study period increased 37% when compared to 2019. The increase in vessel dwell time is likely a result of the 20% increase in container throughput. This leads the research team to believe that the port was not only overloaded by increased ship sailings to the port, but also by elevated throughput volumes. It also shows that the increased spending on durable goods in the United States likely contributed significantly to the inefficient operations experienced at the port. Additionally, the Pearson correlation coefficient of 0.80 indicates a strong, positive correlation between container throughput and vessel dwell time at the Port of Long Beach.

Port of New York and New Jersey

Much like the Port of Long Beach, the Port of New York and New Jersey reportedly suffered from congestion during the pandemic too [96]. Figure 14 displays the 30-day moving average for vessel dwell time for ships at the Port of New York and New Jersey and the 30-day moving average of new Covid cases in New York City. The city had an early surge in Covid cases in spring 2020, as it was one of the first epicenters in the country. It was averaging 2,214 new cases per day between March and May 2020. At the same time the, the vessel dwell time was 2% lower than the January/February average, and 10% lower than the 2019 average of 35 hours. Compared to the previous 3 months, the Covid case average decreased by 84%, and the vessel dwell time increased by 1.6% for June through August 2022. The remainder of the year saw a 382% increase in Covid cases and a 28% increase in dwell times. The Covid situation in New York City remained dire into 2021, cases continued to rise and they peaked in February 2021. The first half of 2021(Jaunary –June) saw a 74% rise in Covid cases and 6.5% rise in vessel dwell times. After a peak in dwell times in January 2021, they levelled off to a little over 43 hours for the entire year of 2021 despite a 24% increase in Covid cases for July-December 2021.In January 2022 a small increase in vessel dwell times seem to coincide with the third surge of Covid cases in New York City. From January 2022 to August 22, 2022, the Covid cases rose by 38% and the vessel dwell time increased by 11%. These observations indicate that there is likely no relationship between local Covid cases and vessel dwell time; i.e. surges in viral infection did not affect port congestion. Additionally, the Pearson correlation coefficient of 0.2 indicates no correlation between local Covid cases and vessel dwell time at the Port of New York and New Jersey.

It can be seen in Figure 15 that the average number of arrivals and departures is right ad 6 ships per day for the entire study period. The average vessel dwell time is 35 hours in 2019. From January through July 2020, the average vessel dwell time is 32 hours. Beginning in August

2020, the vessel dwell time begins a steady increase, and the average from August through December 2020 is 37 hours. From January 2021 through the remainder of the study period, the average dwell time was 10 hours higher than the 2019 average, at 45 hours. Unlike the Port of Long Beach, there is no sharp increase in the average number of ships arriving at the port; but much like the Port of Long Beach, the volume of ships being reported as arriving can be misleading. Once again the ships arriving for unloading at the port are not captured until the ship enters the port. Though there is no data that reports on the number of ships awaiting docking, there are reports in September 2021 and December 2021 of container ships anchoring offshore to await their turn to dock and unload [97] [98]. Included in one of these reports is an explanation for the congestion, which it states is a 20% rise in imports [98]. Once again, it appears that the port became overloaded in the summer of 2020, though this is not reflected in the arrival/departure data. As a result, the vessel dwell times increased and eventually ships were forced to wait at sea for their turn to dock and unload. Observations of the data do not seem to indicate any relationship between ship arrivals/departures and port congestion. Additionally, the Pearson correlation coefficient of 0.07 indicates a lack of any correlation between ship arrivals and vessel dwell time at the Port of New York and New Jersey

Figure 16 displays the connection between vessel dwell times and container throughput. In 2019, the monthly average vessel dwell time was 35 hours and the monthly average container throughput was 622,594 TEU's. When compared to 2019, the container throughput at the port was reduced by 10% between January and July 2020. In this same time period, the average dwell time was also 10% lower compared to 2019. During the first half of 2020, the lower monthly average vessel dwell times correspond with the low throughput numbers. Once again the reduced throughput can be attributed to the pandemic and the massive lockdowns throughout the United States as well as other countries. The total throughput began to rebound in August 2020 and by September the throughput had surpassed any volume previously seen in the study period with 720,969 TEU's. The monthly average container throughput continued to increase and, with February 2021 being the only exception, remained above 709,000 TEU's for the remainder of the study period. From September 2020 through August 2022, the throughput was 21% higher than in 2019 and the average vessel dwell time was 18% higher. These results indicate that the port was overloaded with containers and was unable to keep up with the demands and as a result the port was unable to operate efficiently. Much like the Port of Long Beach, these results also show that the inefficiency at the port is a result of the increased spending on durable goods in the United States. Additionally, the Pearson correlation coefficient of 0.80 represents a moderate to strong correlation between container throughput and vessel dwell time at the Port of New York and New Jersey.

Port of Rotterdam

The Port of Rotterdam is the largest port in Europe. Figure 18 displays the 30-day moving average for vessel dwell time for ships at the Port of Rotterdam and the 30-day moving average of new Covid cases in Rotterdam. Looking at the figure, Rotterdam experienced a mild spring in regards to Covid cases with around 51 new cases per day from March through May 2020. The vessel dwell time during this period was 14.5 hours, or 11% higher than the 2019 average. From June-August, Covid cases were 11% higher, and dwell times were 4.5% lower compared to the previous 3 months. In the fall of 2020, Covid cases in Rotterdam rose by 550% but dwell times decreased by 28%. Compared to the last 3 months of 2020, cases dropped by 40% and dwell times rose by 20% in the first half of 2021. The second half saw Covid cases and vessel dwell times increase by 4.7% and 17.3% respectively. The remainder of the study period, January-August 2022, the city experienced a 208% increase in new daily Covid cases, and a 22% decrease in vessel dwell times. These observations indicate that there is likely no relationship between local Covid cases and vessel dwell time; i.e. surges in viral infection did not affect port efficiency. Additionally, the Pearson correlation coefficient of 0.03 indicates no correlation between local Covid cases and vessel dwell time at the Port of Rotterdam.

It can be seen in Figure 19 that the arrivals and departures is somewhat consistent throughout the study period. The amount of average arrivals per year is 3.2 in 2019, 3.1 in 2020, 2.0 in 2021, and 2.2 in 2022. The port had a yearly average vessel dwell time of 13 hours in 2019 and 2020, 12.7 hours in 2021, and 11.9 hours in 2022. These finding indicate that though the port seemed to experience large fluctuations in arrivals, departures, and dwell time, overall the volume of ships and dwell time were consistent over time. In addition, observations of the data do not seem to indicate any relationship between ship arrivals/departures and port congestion and the Pearson correlation coefficient of 0.18 indicates a lack of correlation between ship arrivals and vessel dwell time at the Port of Rotterdam.

Looking at Figure 20, we can see that the throughput at the port is consistent. The average throughput was 1,241,170 in 2019, 1,203,959 in 2020, 1,275,342 in 2021, and 1,222,421 2022. This is in stark contrast to the port in the United States that experience major increases in throughput starting in the summer/fall of 2020. As said before, the port seemed to experience large fluctuations in the dwell time, but it was consistent over time. The port had a consistent yearly average vessel dwell time of 13 hours in 2019 and 2020, 12.7 hours in 2021, and 11.9 hours in 2022. While throughput at the port and vessel dwell time were consistent, there is lack of evidence to support the presence of a relationship between port congestion and container throughput at the Port of Rotterdam. Additionally, the Pearson correlation coefficient of -0.13 indicates a lack of correlation between container throughput and vessel dwell time at the Port of Rotterdam.

Much like the ports in the United States, the Port of Rotterdam did not seem to be affected by Covid cases in the city or ship arrivals/departures. The major contrast with the U.S. ports is seen in the container throughput and vessel dwell times. The port never experienced the elevated container throughput seen in the United States, which resulted in more consistent vessel dwell times throughout the study period.

Port of Shanghai

The Port of Shanghai is the largest port in the world. It can be seen in Figure 22 that the ship arrivals/departures are consistently around 40 ships per day during the study period. The average ship arrivals were 43 in 2019, 42 in 2020, 41 in 2021, and 40 in 2022. There was an increase in the arrival/departure of ships in late September 2019, with that number increasing up to around 53 ships per day, but that number returned back to 43 by mid-October. The avg. vessel dwell time for the port was 16.6 hours in 2019, 16.2 hours in 2020, 18 hours in 2021, and 17.6 hours in 2022. Additionally, a Pearson correlation coefficient of -0.63 indicates a moderate, negative correlation between ship arrivals and vessel dwell time at the Port of Shanghai.

The average container throughput at the Port of Shanghai was 3,608,583 TEUs in 2019. In the beginning of 2020, the throughput was reduced by 13% due to the pandemic; it quickly-recovered and finished 0.5% higher than 2019. In 2021 the throughput was 8.6% higher than 2019, and in 2022 the throughput was 7.5% higher than 2019. While the amount of throughput did exceed pre-Covid numbers, the percent increase was not like those seen at the ports in the U.S. In addition, there are no major surges in throughput like there was at the ports in the United States. The increase was more gradual. As a result, the Port of Shanghai never became overloaded, and the monthly average vessel dwell time remained consistent from the beginning of the study period, through the pandemic, and to the end of the study period. Observations of the data do not seem to indicate any relationship between container throughput and port congestion. Additionally, the Pearson correlation coefficient of 0.30 indicates that there is no correlation between container throughput and vessel dwell time at the Port of Shanghai.

Much like the other ports, the Port of Shanghai did not seem to be affected by Covid cases in the city nor fluctuations in the ship arrivals/departures. Again, the major contrast with the U.S. ports is seen in the container throughput and vessel dwell times. While the port did experience elevated container throughput like the ports in the United States, the throughput was not as exaggerated and it did not cause the vessel dwell time to increase. When comparing the two ports within the United States to the international ports, we see many differences. First, we can see that vessel dwell times at the Port of Rotterdam and Port of Shanghai never suffered as a result of the pandemic while the vessel dwell times at the Port of Long Beach and Port of New York and New Jersey increased. Next, we can see that container throughput at the ports in the U.S. increased in the summer of 2020 and that this increase coincided with the increased vessel dwell times. At the same time, the other two ports did not see the increase in throughput, or at least not to the same degree, like the two ports in the United States did. It should also be noted, that the two international ports handled much more volume than the U.S. ports and that these ports may be better equipped to handle a large influx cargo in the event of a surge of imports.

7. Conclusions

This research project sought to gain a better understanding of port congestion during the Covid-19 pandemic. In order to accomplish this goal, the research team collected and analyzed Covid data, arrival and departure data of container ships, and container throughout at the Port of Long Beach, Port of New York and New Jersey, Port of Rotterdam, and the Port of Shanghai. These ports were chosen because of their significant roles in the maritime shipping industry. By studying these ports the research team aimed to quantify shipping volume, dwell times, and container throughput at the aforementioned ports; look for trends; seek explanations for the trends; and increase our understanding of the effect that the COVID-19 pandemic had on congestion at the port.

The Port of Long Beach is considered the U.S. gateway for trans-Pacific trade. The port handles trade valued at $200 billion annually. It supports 2.6 million jobs across the nation, 575,000 jobs in Southern California and 50,000, or 1 in 5, in Long Beach. It is one of the few U.S. ports that can handle the largest shipping vessels in the world. Unfortunately, the port suffered some of the worst congestion in the country and was largely blamed for the bottleneck in the supply chain that lead to a delay of everything from durable and non-durable goods, medicine, and food. The research team attempted to observe the possibility that large outbreaks of coronavirus infection in the vicinity of the port may heave lead to an increase in the ship vessel dwell time (amount of time that vessels spend in port actively loading or unloading cargo). It was hypothesized that a large amount of infections would lead to a drop in available workforce, and this would result in increased vessel dwell time. In order to do this, the amount of new daily Covid cases in LA County was plotted along with the average daily vessel dwell time. For each of these data sets, the 30-day average was also plotted. It was observed that the vessel dwell time did increase shortly after the first wave of Covid struck LA County. However, nothing observed, nor the Pearson correlation coefficient indicates that upticks in viral infections caused efficiency to suffer at the Port of Long Beach.

Next, the research team observed the relationship between ship arrivals/departures and vessel dwell time at the Port of Long Beach. The data did show that in summer 2020, an increase in ship arrivals/departures at the port did precede a major uptick in vessel dwell times, but while the ship arrivals dwindled, the vessel dwell times stayed elevated. However, there is likely an explanation for this. As the port became overloaded in the summer of 2020, it was unable to keep up with the demand, efficiency of operation at the port suffered, and congestion occurred. As a result of the congestion, ships that were waiting to enter the port were forced to anchor offshore and wait their turn to enter the port. If the ships could be processed at pre-pandemic levels, then the data would have reflected a higher volume of ship arrivals and departures.

Finally, the research team sought to observe the relationship between container throughput and vessel dwell time at the Port of Long Beach. The data revealed a 20% increase in container throughput at the port between July 2020 and August 2022, and a 37% increase in vessel dwell time between September 2020 and August 2022, compared to 2019. This analysis, along the correlation revealed by the Pearson correlation coefficient, leads the research team to conclude that the increase in container throughput at the Port of Long Beach is a major culprit for the increased vessel dwell times and the resulting port congestion. The Port of Long Beach became overloaded as a result of increased consumer spending on goods during the summer of 2020, this consumption continued afterwards, and the port simply could not keep up with demand.

The Port of New York and New Jersey is the largest port on the east coast and the third largest in the nation. In 2019, the port moved over 7.4 million TEUs of cargo and is considered a gateway to the largest consumer market in North America. The research team attempted to observe the possibility that large outbreaks of coronavirus infection in the vicinity of the port may have lead to an increase in the ship vessel dwell. It was observed that the first surge in Covid cases in New York City did precede the initial increase in vessel dwell time at the Port of New York and New Jersey. However, after Covid cases in the city declined, the vessel dwell time did remain elevated. Also, no subsequent surges in Covid cases resulted in upticks of vessel dwell times. Nothing observed, nor the Pearson correlation coefficient, indicates that upticks in viral infections caused efficiency to suffer at the Port of New York and New Jersey.

Next, the research team attempted to observe the relationship of increased vessel dwell time and an increase in ship arrivals and departures at the Port of New York and New Jersey. Though there was an increase in vessel dwell times that began in the summer of 2020, data did not show an increase in ship arrivals/departures at the port. Much like the Port of Long Beach, there were reports that cargo ships and oil tankers were forced to anchor offshore and wait to dock and unload. There was no data to be found on these ships, but one report states there were at least two dozen ships and tankers anchored offshore [99]. Once again, if the ships were able to be processed at pre-pandemic levels, then it is likely that we would see the increase in ship arrivals/departures reflected in the numbers. Observations of the data, as well as the Pearson correlation coefficient, does not reveal correlation between ship arrivals and vessel dwell time at the Port of New York and New Jersey

Finally, the research team sought to observe the relationship between container throughput and vessel dwell time at the Port of New York and New Jersey. From September 2020 through August 2022, the throughput was 21% higher and the average vessel dwell time was 18% higher than in 2019. This analysis, along with the Pearson correlation coefficient, leads the research team to conclude that the large increase in container throughput at the port is likely the culprit for the increased vessel dwell times. Just like the Port of Long Beach, the pre-pandemic vessel dwell times and container throughput were fairly steady until the summer of 2020, when there was a large increase in throughput at the port up to levels. The amount of throughput was unprecedented. This, along with reports that consumer retail spending skyrocketed shortly after pandemic lockdowns ended and reports of record amounts of throughput at the port, leads us believe that this caused the increase in vessel dwell times. Though the vessel dwell times were not nearly as bad as in Long Beach, the Port of New York and New Jersey also became overloaded as a result of increased consumer spending on goods during the summer of 2020, this continued throughout the study period, and the port simply could not keep up with demand and became congested.

The Port of Rotterdam is the largest seaport in Europe and the largest seaport outside of East Asia. It is considered Europe’s gateway to the world. The research team attempted to observe the possibility that large outbreaks of coronavirus infection in the vicinity of the port may heave lead to an increase in the ship vessel dwell. Nothing observed, nor the Pearson correlation coefficient, indicates any correlation between local Covid cases and vessel dwell time at the Port of Rotterdam.

Next, the research team attempted to observe the relationship of increased vessel dwell time and an increase in ship arrivals and departures at the Port of Rotterdam. Again, there was never a significant increase in ship arrivals that resulted in increased vessel dwell times. In fact, arrivals and departures decreased slightly over the study period, while the vessel dwell times hover around the same time throughout the study period. Nothing observed, nor the Pearson correlation coefficient, indicates any correlation between ship arrivals/departures and vessel dwell time at the Port of Rotterdam.

Finally, the research team sought to observe the relationship between container throughput and vessel dwell time at the Port of Rotterdam. Nothing observed, nor the Pearson correlation coefficient, indicates any correlation between container throughput and vessel dwell time at the Port of Rotterdam. From the data, we can conclude that there was no surge in consumer spending that resulted in elevated container throughput at the port. Generally, speaking, we can also conclude that the vessel dwell times at the Port of Rotterdam never suffered because of the pandemic.

The Port of Shanghai, located in Shanghai, China, is the busiest port in the world in terms of cargo tonnage. It has handled the most container throughput in the world for 13 years straight. Due to unreliable Covid case data, we are unable to make any conclusion regarding the relationship between viral infection outbreaks and increased vessel dwell times.

Next, the research team attempted to observe the relationship of increased vessel dwell time and an increase in ship arrivals and departures at the Port of Shanghai. Though there were some spikes and dips in arrivals/departures throughout the study period, the data is pretty consistent. The average ship arrivals were 43 in 2019, 42 in 2020, 41 in 2021, and 40 in 2022. The average vessel dwell time for the port was 16.6 hours in 2019, 16.2 hours in 2020, 18 hours in 2021, and 17.6 hours in 2022. Interestingly, the Pearson correlation coefficient indicates a moderate, negative correlation between ship arrivals and vessel dwell time at the Port of Shanghai.

Finally, the research team sought to observe the relationship between container throughput and vessel dwell time at the Port of Shanghai. In 2021 the throughput was 8.6% higher than 2019, and in 2022 the throughput was 7.5% higher than 2019. While the amount of throughput did exceed pre-Covid numbers, the percent increase was not like those seen at the ports in the U.S. Nothing on the data, nor the Pearson correlation coefficient, indicate a correlation between container throughput and vessel dwell time. Generally, speaking, we can be conclude that the vessel dwell times at the Port of Shanghai never suffered as a result of the pandemic.

When comparing the ports in the United States to the ports abroad, the efficiency at the U.S ports suffered immensely as a result of the pandemic. Though there are many explanations for this, the data observed in this research study concludes that there was a massive influx of goods at the ports which is reflected in the container throughput. As a result, the ports became overloaded and were unable to keep up with demand. The ports became congested, efficiency declined and vessel dwell times skyrocketed. As a result of this congestion, ships sailing for the Port of Long Beach and Port of New York and New Jersey were forced to anchor offshore and wait to unload. This occurred due changes in societal norms from the pandemic and resulted in a massive swing from services to goods. Unlike the U.S. ports, the ports in Rotterdam and Shanghai never saw this increased throughput and continued to operate efficiently throughout the study period.

The implications of this research are that the ports in the U.S. are susceptible to the fluctuations in the consumer spending model. Though the pandemic was unprecedented, the spending habits of people in the United States can be unpredictable and surges in consumption can lead to supply chain bottlenecks at the ports. This could happen as a result of many things such as natural disaster, terrorist attacks, stimulus checks, or tax cuts. In order to combat this vulnerability, research on improving resiliency and efficiency at ports should be conducted.

8. References

[1] D. Cucinotta and M. Vanelli, "WHO Declares COVID-19 a Pandemic," *Acta bio-medica : Atenei Parmensis,* vol. 91, no. 1, pp. 157-160, 2020.

[2] K. Liptak, "Trump declares national emergency—and denies responsibility for coronavirus testing failures," CNN, 13 March 2020. [Online]. Available: https://www.cnn.com/2020/03/13/politics/donald-trump-emergency/index.html. [Accessed 5 December 2022].

[3] United Nations World Tourism Organization, "COVID-19 RESPONSE: 96% OF GLOBAL DESTINATIONS IMPOSE TRAVEL RESTRICTIONS, UNWTO REPORTS," UNWTO, 17 April 2020. [Online]. Available: https://www.unwto.org/news/covid-19-response-travel-restrictions. [Accessed 5 December 2022].

[4] Crude oil WTI price data, [Online]. Available: https://www.investing.com/commodities/crude-oil. [Accessed 27 July 2022].

[5] M. Rapaccini, N. Saccani, C. Kowalkowski, M. Paiola and F. Adrodegari, "Navigating disruptive crises through service-led growth: The impact of COVID-19 on Italian manufacturing firms," *Ind. Market. Manag,* vol. 88, pp. 225-237, 2020.

[6] U.S. Bureau of Labor Statistics, "Employment Recovery in the wake of the Covid-19 Pandemic bls.gov," December 2020. [Online]. Available: https://www.bls.gov/opub/mlr/2020/article/employment-recovery.htm#_edn24. [Accessed 28 July 2022].

[7] L. M. Millefiori, P. Braca, D. Zissis, G. Spiliopoulos, S. Marano, P. Willett and S. Carniel, "Covid-19 impact on global maritime mobility," *Scientific Report,* vol. 11, no. 18039, 2021.

[8] J. K. Jackson, M. A. Weiss, A. B. Schwarzenberg, R. M. Nelson, K. M. Sutter and M. D. Sutherland, "Global Economic Effects of Covid-19," Congressional Research Service, Washington, D.C., 2021.

[9] G. M. Magableh, "Supply Chains and the COVID-19 Pandemic:," *European Management Review,* vol. 18, pp. 363-3682, 2021.

[10] Blume Global, "The Supply Chain, Explained," [Online]. Available: https://www.blumeglobal.com/learning/supply-chain-explained/. [Accessed 7 December 2022].

[11] United Nations Conference on Trade and Development, "Covid-19 and maritime transport: Impact and responses," Geneva, 2020.

[12] "Maritime Transportation System (MTS) Improving the U.S. Marine Transportation System," U.S. Department of Transportation Maritime Administration, 8 January 2021. [Online]. Available: https://www.maritime.dot.gov/outreach/maritime-transportation-system-mts/maritime-transportation-system-mts. [Accessed 29 July 2022].

[13] A. Komaromi, D. A. Cerdeiro and Y. Liu, "Supply Chains and Port Congestion Around the World," International Monetary Fund, Washington, D.C., 2022.

[14] CalChamber, "Global Supply Chains and Port," in *Agenda for California Recovery: 2022 Business Issues and Legislative Guide*, Los Angeles, 2022.

[15] M. Jones, "Snarled-up ports point to worsening global supply chain woes - report," Reuters, 3 May 2022. [Online]. Available: https://www.reuters.com/business/snarled-up-ports-point-worsening-global-supply-chain-woes-report-2022-05-03/. [Accessed 31 January 2023].

[16] T. Sterling, "Congestion at Port of Rotterdam seen persisting through 2022," Reuters, 11 November 2021. [Online]. Available: https://www.reuters.com/article/port-of-rotterdam-congestion/congestion-at-port-of-rotterdam-seen-persisting-through-2022-idUSL1N2S210K. [Accessed 2 February 2023].

[17] A. Fleck, "Shanghai Ship Jam Spells Supply Chain Trouble," statista, 28 April 2022. [Online]. Available: https://www.statista.com/chart/27343/container-ship-backlog-off-shanghai-port/. [Accessed 1 February 2023].

[18] K. Tauber and W. Van Zandweghe, "Why Has Durable Goods Spending Been So Strong during the COVID-19 Pandemic?," *Economic Commentary,* vol. 2021, no. 16, pp. 1-7, 2021.

[19] M. Brewster, "E-Commerce Sales Surged During the Pandemic," U.S. Census Bureau, 27 April 2022. [Online]. Available: https://www.census.gov/library/stories/2022/04/ecommerce-sales-surged-during-pandemic.html#:~:text=According%20to%20the%20most%20recent,to%20%24815.4%20billion%20in%202020.. [Accessed 1 February 2023].

[20] J. Frittelli and L. Wong, "Supply Chain Bottlenecks at U.S. Ports," Congressional Research Service, Washington, D.C., 2021.

[21] American Trucking Associations, "Supply Chain Watch," [Online]. Available: https://www.trucking.org/supplychain#:~:text=America's%20trucking%20industry%20is%20a,shipped%20in%20the%20United%20States.. [Accessed 1 February 2023].

[22] American Trucking Associations, "Industry Short 80,000 Drivers Today, May Be Short 160,000 by 2030," 21 October 2021. [Online]. Available: https://www.trucking.org/news-insights/ata-chief-economist-pegs-driver-shortage-historic-high. [Accessed 1 February 2023].

[23] W. Dortch, K. Keller and M. Van Hattem, "Delivering Supply Chain Relief for Ports Through Pop-Up Container Yards," HDR, 7 March 2022. [Online]. Available: https://www.hdrinc.com/insights/delivering-supply-chain-relief-ports-through-pop-container-yards. [Accessed 1 February 2023].

[24] S. Qui, S. Singh and R. Khasawneh, "Boxed out: China's exports pinched by global run on shipping containers.," Reuters, 10 December 2020. [Online]. Available: https://www.reuters.com/article/us-global-shipping-container/boxed-out-chinas-exports-pinched-by-glob-al-run-on-shipping-containers-idUSKBN28K0UA. [Accessed 2 February 2023].

[25] A. Toygar, U. Yildrim and G. M. Inegol, "Investigation of empty container shortage based on SWARA-ARAS methods in the COVID-19 era," *European Transport Research Review,* vol. 14, no. 8, pp. 1-17, 2022.

[26] F. Holmes, "Container Ship Operators Are On A Tear As Freight Rates Skyrocket," Forbes, 25 March 2021. [Online]. Available: https://www.forbes.com/sites/greatspeculations/2021/03/25/container-ship-operators-are-on-a-tear-as-freight-rates-skyrocket/?sh=50c588c639a6. [Accessed 2 February 2023].

[27] S. Steinbach, "Port congestion, container shortages, and U.S. foreign trade," *Economics Letters,* vol. 213, 2022.

[28] P. Stevens, "The ship that blocked the Suez Canal may be free, but experts warn the supply chain impact could last months," CNBC, 29 March 2021. [Online]. Available: https://www.cnbc.com/2021/03/29/suez-canal-is-moving-but-the-supply-chain-impact-could-last-months.html. [Accessed 1 February 2023].

[29] National Centers for Environmental Information, "Billion-Dollar Weather and Climate Disasters," NOAA, 10 January 2023. [Online]. Available: https://www.ncei.noaa.gov/access/billions/time-series. [Accessed 1 February 2023].

[30] U.S. Chamber of Commerce, "How Government Benefits Programs Are Contributing to the Labor Shortage," 29 September 2022. [Online]. Available: https://www.uschamber.com/workforce/data-deep-dive-how-government-benefits-programs-are-contributing-to-the-labor-shortage. [Accessed 1 February 2023].

[31] M. Placek, "statista.com," September 2022. [Online]. Available: https://www.statista.com/statistics/1182233/impact-covid-19-supply-chain/. [Accessed 7 December 2022].

[32] C. Paris, "Shipments Delayed: Ocean Carrier Shipping Times Surge in Supply-Chain Crunch," The Wall Street Journal, 18 May 2021. [Online]. Available: https://www.wsj.com/articles/shipments-delayed-ocean-carrier-shipping-times-surge-in-supply-chain-crunch-11621373426. [Accessed 2 February 2023].

[33] D. Macaluso and M. McMahon, "What is supply chain inflation and why is it driving up consumer prices now?," Economics Observatory, 21 January 2022. [Online]. Available:

https://www.economicsobservatory.com/what-is-supply-chain-inflation-and-why-is-it-driving-up-consumer-prices-now. [Accessed 21 February 2023].

[34] C. Austin, "How the supply chain caused current inflation, and why it might be here to stay," PBS News Hour, 10 November 2021. [Online]. Available: https://www.pbs.org/newshour/economy/how-the-supply-chain-caused-current-inflation-and-why-it-might-be-here-to-stay. [Accessed 2 February 2023].

[35] L. Xu, J. Shi, J. Chen and L. Li, "Estimating the effect of COVID-19 epidemic on shipping trade: An empirical analysis using panel data," *Marine Policy,* vol. 133, 2021.

[36] H.-M. Zhao, H.-D. He, K.-F. Lu, X.-L. Han, Y. Ding and Z.-R. Peng, "Measuring the impact of an exogenous factor: An exponential smoothing model of the response of shipping to COVID-19," *Transport Policy,* vol. 118, pp. 99-100, 2022.

[37] A. Alamoush, A. I. Olcer and F. Ballini, "Ports, maritime transport, and industry: The immediate impact of COVID-19 and the way forward," *Maritime Technology and Research,* vol. 4, 2022.

[38] D. Guerrero, L. Letrouit and C. Pais-Montes, "The container transport system during Covid-19: An analysis through the prism of complex networks," *Transport Policy,* vol. 115, pp. 113-125, 2022.

[39] C. Dirzka and M. Acciaro, "Global shipping network dynamics during the COVID-19 pandemic's initial phases," *Journal of Transport Geography,* vol. 99, no. 103265, 2022.

[40] D. Guan, D. Wang , S. Hallegatte, S. J. Davis, J. Huo, S. Li, Y. Bai, Q. Xue, D. Coffman, D. Cheng, P. Chen, X. Liang, B. Xu, X. Lu, S. Wang, K. Hubacek and P. Gong, "Global supply-chain effects of COVID-19 control measures," *Nature Human Behaviour ,* vol. 4, pp. 577-587, 2020.

[41] Z. Tai, J. Guo, Y. Guan and Q. Shi, "Impact of COVID-19 on Port Production and Operation Based on System Dynamics: A Case Study of Shanghai Port in China," *Journal of Advanced Transportation,* vol. 2021, p. 13, 2021.

[42] O. Osundiran, F. Okunta and H. Quainoo, "An Examination of the Impact of Covid-19 Pandemic on the Maritime Port of Singapore Container Port Productivity using Malmquist Productivity Index," *Journal of Maritime & Transportation Sciences,* vol. 60, no. 1, pp. 85-96, 2021.

[43] D. Gui, H. Wang and M. Yu, "Risk Assessment of Port Congestion Risk during the COVID-19 Pandemic," *Journal of Marine Science and Engineering,* vol. 10, no. 2, 2022.

[44] D. Russell, K. Ruamsook and V. Roso, "Managing supply chain uncertainty by building flexibility in container port capacity: a logistics triad perspective and the COVID-19 case," *Maritime Economics & Logistics,* vol. 24, pp. 92-113, 2022.

[45] B. Su, C. Guan, Q. An and Q. Wang, "Analysis and Countermeasures of the Influence of COVID-19 on the Commodity Category of Port Export in China: Taking Shanghai Port as an Example," *Journal of Coastal Research,* vol. 111, no. sp1, pp. 298-301, 2020.

[46] T. Notteboom, T. Pallis and J.-P. Rodrigue, "Disruptions and resilience in global container shipping and ports: the COVID-19 pandemic versus the 2008–2009 financial crisis," *Maritime Economics and Logistics,* vol. 23, pp. 179-210, 2021.

[47] H. Abous, M. Hamiche and M. El Merouani, "The impact of Covid-19 on the port environment: The case of Tanger Med container port, Morocco," *E3S Web Conf.,* vol. 234, p. 25, 2021.

[48] V. Bosco and C. Nicholson, "Port disruption impact on the maritime supply chain: a literature review," *Sustainable and Resilient Infrastructure,* vol. 5, pp. 1-17, 2019.

[49] M. Svanberg, H. Holm and K. Cullinane, "Assessing the Impact of Disruptive Events on Port Performance," *Journal of,* vol. 9, p. 145, 2021.

[50] J. Verschuur, E. Koks and J. Hall, "Port disruptions due to natural disasters: Insights into port and logistics resilience," *Transportation Research Part D: Transport and Environment,* vol. 85, p. 102393, 2020.

[51] C. Caballini, H. Ghiara and L. Persico, "Analysis of the impacts of COVID-19 on selected categories of goods passing through the ports of Genoa and Savona, Italy," *Case Studies on Transport Policy,* vol. 10, no. 2, pp. 851-869, 2022.

[52] X. Wang, Z. Liu, R. Yan, H. Wang and M. Zhang, "Quantitative analysis of the impact of COVID-19 on ship visiting behaviors to ports- A framework and a case study," *Ocean & Coastal Management,* vol. 230, 2022.

[53] S. Hanson, R. Nicholls, N. Ranger, S. Hallegatte, J. Corfee-Morlot, C. Herweijer and J. Chateau, "A global ranking of port cities with high exposure to climate extremes," *Climatic Change,* vol. 104, pp. 89-111, 2011.

[54] H. S. Loh and V. V. Thai, "Cost Consequences of a Port-Related Supply Chain Disruption," *The Asian Journal of Shipping and Logistics,* vol. 31, no. 3, pp. 319-340, 2015.

[55] J. di Giovanni, S. Kalemli-Ozcan, A. Silva and M. A. Yildirim, "Global Supply Chain Pressures, International Trade, and Inflation," *Federal Reserve Bank of New York Staff Reports,* vol. 1024, 2022.

[56] A. M. Santacreu and . L. Jesse, "Global Supply Chain Disruptions and Inflation During the COVID-19 Pandemic," *Federal Reserve Bank of St. Louis Review,* vol. 104, no. 2, pp. 78-91, 2022.

[57] Subcommittee on Coast Guard and MAritime Transportation, "Impacts of Shipping Conatiner Shortages, Delays, and Increased Demand on the North American Supply Chain," Washington, D.C., 2021.

[58] Port of Long Beach, "EXPLORE THE PORT OF LONG BEACH," Port of Long Beach, [Online]. Available: https://polb.com/port-info. [Accessed 3 February 2023].

[59] Port of New York and New Jersey, "Facts and Figures," [Online]. Available: https://www.panynj.gov/port/en/our-port/facts-and-figures.html. [Accessed 3 February 2023].

[60] Choose New Jersey, "New Jersey Business," [Online]. Available: https://www.choosenj.com/news/port-of-ny-nj-becomes-countrys-second-largest-container-port/. [Accessed 3 February 2023].

[61] Port of Rotterdam, "Facts and Figures. A wealth of information.," 2022. [Online]. Available: https://www.portofrotterdam.com/sites/default/files/2022-11/facts-and-figures-port-of-rotterdam_0.pdf. [Accessed 5 February 2023].

[62] Ship Technology, "Port of Rotterdam," Verdict Media Limited, 4 October 2010. [Online]. Available: https://www.ship-technology.com/projects/portofrotterdam/. [Accessed 6 February 2023].

[63] Ship Technology, "Port of Shanghai," Verdict Media, 6 March 2020. [Online]. Available: https://www.ship-technology.com/projects/portofshnaghai/. [Accessed 6 February 2023].

[64] Ship Hub, "The Port of Shanghai," [Online]. Available: https://www.shiphub.co/port-of-shanghai/. [Accessed 6 February 2023].

[65] Shipping Watch, "Shanghai is busiest container port for 13th consecutive year," 1 January 2023. [Online]. Available: https://shippingwatch.com/Ports/article14778401.ece. [Accessed 6 February 2023].

[66] U.S. Department of Transportation Bureau of Transportation Statistics, "Container Vessel Dwell Times," October 2022. [Online]. Available: https://data.bts.gov/stories/s/Container-Vessel-Dwell-Times/pbag-pyes#:~:text=Vessel%20dwell%20times%20are%20the,costs%20rise%20with%20dwell%20time.. [Accessed 18 March 2023].

[67] United States Census Bureau, "Census Bureau QuickFacts," 1 7 2022. [Online]. Available: https://www.census.gov/quickfacts/fact/dashboard/longbeachcitycalifornia/PST045222. [Accessed 24 6 2023].

[68] City of Long Beach, "Press Release: City of Long Beach Health Department Monitoring Coronavirus Outbreak in China," Public Information Office, Long Beach, 2020.

[69] City of Long Beach, "Press Release: Long Beach Announces First Cases of COVID-19," Public Information Office, Long Beach, 2020.

[70] Los Angeles County Department of Public Health , "Press Release: LA County Public Health Issues Order to Prohibit Group Events and Gatherings, Require Social Distancing Measures and the Closure of Certain Businesses," Los Angeles County Department of Public Health , Los Angeles, 2020.

[71] Associated Press, "California governor issues statewide stay-at-home order," 19 March 2020. [Online]. Available: https://apnews.com/article/health-us-news-ap-top-news-virus-

outbreak-gavin-newsom-9ca4a191790dd6f80bd5acec569ec423. [Accessed 20 June 2023].

[72] City News Service, "Garcetti Says Restaurants, Barbershops Can Reopen Under Limited Capacity," NBC, 29 May 2020. [Online]. Available: https://www.nbclosangeles.com/news/local/garcetti-says-restaurants-barbershops-can-reopen-under-limited-capacity/2370814/. [Accessed 24 June 2023].

[73] J. Kandel, "Timeline: A Look at Key Coronavirus Pandemic Events and Milestones in California," NBC, 22 December 2021. [Online]. Available: https://www.nbclosangeles.com/news/coronavirus/2020-2021-california-coronavirus-pandemic-timeline-key-events/2334100/. [Accessed 24 June 2023].

[74] City News Service, "LA County Enacts New Stay-at-Home Order as COVID-19 Cases Spike," NBC, 27 November 2020. [Online]. Available: https://www.nbclosangeles.com/news/coronavirus/la-county-enacts-new-stay-at-home-order-as-covid-19-cases-spike/2472327/. [Accessed 24 June 2023].

[75] City News Service, "Los Angeles County Begins to Loosen COVID-19 Restrictions," NBC, 25 January 2021. [Online]. Available: https://www.nbclosangeles.com/news/local/los-angeles-county-begins-to-loosen-covid-restrictions/2512012/?_osource=SocialFlowTwt_LABrand. [Accessed 24 June 2023].

[76] B. Levesque, "LOS ANGELES COUNTY250,000 COVID cases over past 7 days, unvaccinated at extreme risk," Los Angeles Blade, 22 January 2022. [Online]. Available: https://www.losangelesblade.com/2022/01/22/250000-covid-cases-over-past-7-days-unvaccinated-at-extreme-risk/. [Accessed 24 June 2023].

[77] United States Census Bureau, "Census Bureau QuickFacts," 1 July 2022. [Online]. Available: https://www.census.gov/quickfacts/fact/table/newyorkcitynewyork/PST045222. [Accessed 25 June 2023].

[78] Statista Research Department, "Population of the New York-Newark-Jersey City metro area in the United States from 2010 to 2021," 2 June 2023. [Online]. Available: https://www.statista.com/statistics/815095/new-york-metro-area-population/#:~:text=In%202021%2C%20about%2019.77%20million,that%20lived%20there%20in%202010.. [Accessed 25 June 2023].

[79] M. Sinai, "Press Release: Mount Sinai Study Finds First Cases of COVID-19 in New York City are Primarily from European and US Sources," 2 June 2020. [Online]. Available: https://www.mountsinai.org/about/newsroom/2020/mount-sinai-study-finds-first-cases-of-covid-19-in-new-york-city-are-primarily-from-european-and-us-sources-pr. [Accessed 25 June 2023].

[80] P. Adcroft and F. Toor, "Timeline: How COVID-19 Changed NY," 11 March 2022. [Online]. Available: https://www.ny1.com/nyc/all-boroughs/news/2021/03/10/timeline--how-covid-19-changed-nyc. [Accessed 25 June 2023].

[81] New York State, "Governor Cuomo Signs the 'New York State on PAUSE' Executive Order," 20 March 2020. [Online]. Available: https://www.governor.ny.gov/news/governor-cuomo-signs-new-york-state-pause-executive-order#:~:text=It%20includes%20a%20new%20directive,any%20size%20for%20any%20reason.. [Accessed 25 June 2023].

[82] A. Liveris, M. Stone, H. Markel, G. Agriantonis, M. Bukur, S. Roudnitsky, E. Chao, S. Reddy, S. Teperman and J. Meltzer, "When New York City was the COVID-19 pandemic epicenter: The impact on trauma care," *The journal of trauma and acute care surgery,* vol. 93, no. 2, pp. 247-255, 2022.

[83] A. Kerr, "A Historical Timeline of COVID-19 in New York City," 15 April 2021. [Online]. Available: https://www.investopedia.com/historical-timeline-of-covid-19-in-new-york-city-5071986. [Accessed 25 June 2023].

[84] Statista Research Department, "Total population of Rotterdam from 2009 to 2022," Statista, 1 September 2022. [Online]. Available: https://www.statista.com/statistics/753250/total-population-of-rotterdam/. [Accessed 26 June 2023].

[85] Reuters Staff, "France confirms first three cases of coronavirus in Europe," Reuters, 24 January 2020. [Online]. Available: https://www.reuters.com/article/china-health-france/update-2-france-confirms-first-three-cases-of-coronavirus-in-europe-idUSL8N29T5F4. [Accessed 25 June 2024].

[86] Dutch News, "Coronavirus: A timeline of the pandemic in the Netherlands," Dutch News, 16 May 2020. [Online]. Available: https://www.dutchnews.nl/2020/05/coronavirus-a-timeline-of-the-pandemic-in-the-netherlands/. [Accessed 25 June 2023].

[87] NL Times, "First coronavirus fatality in Netherlands: Rotterdam patient dead at 86," NL Times, 6 March 2020. [Online]. Available: https://nltimes.nl/2020/03/06/first-coronavirus-fatality-netherlands-rotterdam-patient-dead-86. [Accessed 25 June 2023].

[88] M. de Haas, R. Faber and M. Hamersma, "How COVID-19 and the Dutch ‘intelligent lockdown’ change activities, work and travel behaviour: Evidence from longitudinal data in the Netherlands," *Transportation Research Interdisciplinary Perspectives,* vol. 6, 2020.

[89] Rijksoverheid, "Positive tests in Rotterdam," Rijksoverheid, [Online]. Available: https://coronadashboard.government.nl/gemeente/GM0599/positief-geteste-mensen. [Accessed 25 June 2023].

[90] S. Austin, "The 10 Largest Cities in the World," U.S. News and World Report, 6 April 2023. [Online]. Available: https://www.usnews.com/news/cities/slideshows/the-10-largest-cities-in-the-world?slide=9. [Accessed 26 June 2023].

[91] Y. Shen, F. Zheng, D. Sun, Y. Ling , J. Chen, F. Li, T. Li, Z. Qian, Y. Zhang, Q. Xu, L. Liu, Q. Huang, F. Shan, L. Xu, J. Wu, Z. Zhu, Z. Song, S. Li, Y. Shi, J. Zhang and H. Lu,

"Epidemiology and clinical course of COVID-19 in Shanghai, China," *Emerging microbes & infections,* vol. 9, no. 1, pp. 1537-1545, 2020.

[92] "Epidemiological characteristics and transmission dynamics of the outbreak caused by the SARS-CoV-2 Omicron variant in Shanghai, China: A descriptive study," *The Lancet Regional Health - Western Pacific,* vol. 20, 2022.

[93] Associated Press, "Shanghai Starts China's Biggest COVID-19 Lockdown in 2 Years," The Diplomat, 29 March 2022. [Online]. Available: https://thediplomat.com/2022/03/shanghai-starts-chinas-biggest-covid-19-lockdown-in-2-years/. [Accessed 1 July 2023].

[94] D. Stanway, "Explainer: Shanghai death numbers raise questions over its COVID accounting," Reuters, 28 April 2022. [Online]. Available: https://www.reuters.com/world/china/shanghai-death-numbers-raise-questions-over-its-covid-accounting-2022-04-28/. [Accessed 1 July 2023].

[95] City News Service, "Port of Long Beach has busiest year with 9M cargo containers processed," Spectrum News 1, 19 January 2022. [Online]. Available: https://spectrumnews1.com/ca/la-west/transportation/2022/01/20/port-of-long-beach-has-busiest-year-with-9m-cargo-containers-processed. [Accessed 18 April 2023].

[96] P. Berger, "Shipping Bottlenecks Hit Port of New York and New Jersey," The Wall Street Journal, 18 May 2022. [Online]. Available: https://www.wsj.com/articles/shipping-bottlenecks-hit-port-of-new-york-and-new-jersey-11652902981. [Accessed 26 April 2023].

[97] M. Angell, "Ships begin backing up at NY-NJ amid cargo surge," Journal of Commerce, 27 September 2021. [Online]. Available: https://www.joc.com/article/ships-begin-backing-ny-nj-amid-cargo-surge_20210927.html. [Accessed 30 April 2023].

[98] M. Angell, "NY-NJ vessel backlog creeps back up amid bigger ship calls," Journal of Commerce, 22 December 2021. [Online]. Available: https://www.joc.com/article/ny-nj-vessel-backlog-creeps-back-amid-bigger-ship-calls_20211222.html. [Accessed 30 April 2023].

[99] A. Zilber, S. Farberov and J. Gordon, "Dozens of ships are forced to anchor off coast of New York as they wait to dock in the country's second-largest port - adding to US supply chain crunch which has forced FedEx to reroute 600k packages a day," DailyMail, 25 September 2021. [Online]. Available: https://www.dailymail.co.uk/news/article-10029043/Dozens-ships-coast-New-York-wait-dock-countrys-second-largest-port.html. [Accessed 1 July 2023].