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DISRUPTIONS IN MARITIME TRANSPORT:

AN AIS-BASED ANALYSIS OF MARITIME EVENTS

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Abstract

Maritime transport is a cornerstone of global trade, yet it faces increasing vulnerability to various disruptions. This thesis analyzes maritime disruption dynamics and their impact on vessel traffic using a framework based on Automatic Identification System (AIS) data. The study aims to categorize different types of shocks and evaluate how maritime networks respond in terms of intensity, duration, and spatial manifestation.

The methodology adopts a case-study approach, examining twelve significant events across the United States and Denmark. These cases are grouped into six categories: natural disasters, geopolitical events, economic shocks, technological incidents, maritime accidents, and labour disputes. By utilizing AIS-based indicators, specifically daily vessel counts and impact deviations the research, quantifies operational shifts in vessel presence relative to established traffic baselines.

The findings identify four distinct functional response patterns: infrastructure capacity shocks, demand-driven disruptions, structural trade rerouting, and temporary operational volatility. Results indicate that infrastructure failures generate immediate congestion effects, while geopolitical shocks lead to longer-term structural rerouting of maritime trade flows. In contrast, technological disruptions and localized labour disputes primarily generate short-term volatility that the maritime system absorbs through operational flexibility.

The study concludes that the structural role of a port within the global maritime network significantly influences the scale of disruption impacts. These findings highlight the value of AIS-based monitoring for proactive risk management and for strengthening the resilience of international shipping networks.

Key Words:

Maritime Transport, Supply Chain Disruptions, AIS Data, Maritime Networks, Vessel Traffic Analysis

List Of Abbreviations

AIS	Automatic Identification System
APMT	APM Terminals
EEZ	Exclusive Economic Zone
EEXI	Energy Efficiency Existing Ship Index
ILWU	International Longshore and Warehouse Union
IMO	International Maritime Organization
LA-LB	Los Angeles - Long Beach
LNG	Liquefied Natural Gas
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MMSI	Maritime Mobile Service Identity
NOAA	National Oceanic and Atmospheric Administration
NY-NJ	New York - New Jersey
OECD	Organisation for Economic Co-operation and Development
PMA	Pacific Maritime Association
UNCTAD	United Nations Conference on Trade and Development
USD	United States Dollar

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1. Introduction

Maritime transport plays a fundamental role in the global economy and international trade. A large share of goods traded worldwide is transported by sea due to the efficiency and cost advantages offered by maritime shipping. Container shipping in particular has become a key component of global logistics systems, enabling the movement of raw materials, intermediate products, and finished goods between continents. Modern maritime transport networks connect ports across different regions of the world and support the functioning of global supply chains.

Within the maritime transport sector, liner shipping services constitute one of the most important operational models. Liner shipping refers to scheduled maritime transport services operating on fixed routes between predetermined ports. These services are designed to provide regular and reliable connections between major trade regions. Through such networks, shipping companies facilitate the movement of containerized cargo and sustain the continuity of international trade flows.

Despite the efficiency of modern maritime transport systems, shipping networks are increasingly exposed to disruptions originating from a variety of sources. These disruptions may arise from natural disasters, geopolitical conflicts, technological failures, cyberattacks, economic crises, or operational incidents. When such events occur, they may affect vessel schedules, port operations, and logistics chains, creating delays and operational inefficiencies within global supply networks.

The growing complexity and interconnectivity of global supply chains mean that disruptions occurring in one location may propagate across maritime transport networks and affect multiple regions. As a result, disruptions in maritime transport can generate significant operational and economic consequences for shipping companies, ports, and logistics stakeholders.

Recent global events have further demonstrated the vulnerability of maritime transport systems to unexpected disruptions. Events such as pandemics, geopolitical tensions, and cyber incidents have shown that disruptions can significantly affect shipping operations and maritime logistics. These developments have increased the importance of studying disruption dynamics and understanding how maritime transport systems respond to such events.

1.1 Disruptions in Maritime Transport

Disruptions in maritime transport can take many forms and may originate from different sources. Natural disasters such as earthquakes, storms, and extreme weather conditions may damage port infrastructure or temporarily interrupt vessel traffic. Geopolitical tensions and conflicts may also affect maritime transport by creating security risks in strategic shipping routes or by restricting international trade flows.

Technological failures and cyber incidents represent another source of disruption in modern maritime transport systems. As shipping operations increasingly rely on digital technologies and information systems, cyber risks have become an important concern for maritime security and operational stability within global shipping networks.

In addition to external events, disruptions may also arise from operational challenges within shipping networks. Port congestion, labour disputes, and infrastructure failures may affect vessel schedules and create delays in liner shipping services. Since liner shipping networks operate according to fixed schedules and interconnected port calls, disruptions affecting one part of the network may influence subsequent operations across the wider maritime transport system.

Understanding the nature and sources of maritime disruptions is therefore essential for evaluating their potential impact on shipping networks and maritime logistics systems.

1.2 Impact of Disruptions on Shipping Networks

Disruptions may have significant implications for the performance and reliability of shipping networks. When unexpected events occur, vessel schedules may be delayed and port operations may be affected. Such disruptions may create congestion in ports, delays in cargo handling, and interruptions in logistics chains.

Because liner shipping services operate according to fixed schedules and predefined routes, disruptions affecting one port or maritime corridor may propagate through the network and influence subsequent port calls. Shipping companies may therefore need to adopt operational adjustments in order to restore service reliability and minimize delays.

In some cases, disruptions affecting strategic maritime routes may have broader consequences for global maritime transport. When major maritime corridors are affected, shipping companies may be forced to alter their routes, adjust their schedules, or reorganize their service networks. Such adjustments may increase transportation distances, operational costs, and transit times.

These dynamics highlight the importance of understanding how disruptions influence shipping networks and how maritime transport systems adapt in order to maintain operational continuity.

1.3 Research Objectives and Scope

The main objective of this thesis is to examine disruptions affecting maritime transport systems and to analyse their implications for shipping networks and vessel operations.

More specifically, I aim to identify major types of disruptions affecting maritime transport and I examine how such events influence vessel operations and shipping network performance. By analysing disruption events in maritime transport,I seek to contribute to a better understanding of resilience and operational adaptation within maritime logistics systems.

The scope of the research focuses on disruption events that influence maritime transport operations and shipping network dynamics.

1.4 Structure of the Thesis

The remainder of this thesis is organized as follows.

Chapter 2 I present the literature review and discuss previous research on maritime transport disruptions and shipping network resilience.

Chapter 3 I describe the research methodology and analytical framework used in the study.

Chapter 4 I present the disruption case analysis and examine the impact of selected disruption events on maritime transport operations.

Finally, Chapter 5 summarizes the main findings of the research and discuss their implications for maritime transport resilience and future research.

2. Literature review

2.1 Disruptions in Maritime Transportation

Maritime transport remains the backbone of global trade, carrying over 80% of internationally traded goods by volume and approximately 70% by value, a share that has remained broadly stable over recent years (Notteboom et al. 2024; UNCTAD, 2024). Despite major disruptions between 2019 and 2024, including the COVID-19 pandemic, the Russia/Ukraine war, and heightened security threats in the Red Sea, global seaborne trade has demonstrated notable resilience in aggregate terms. However, while overall trade volumes have been largely sustained, the reliability, frequency, and cost-efficiency of maritime services have deteriorated significantly during these crises.In this context, Ksciuk et al. (2023) highlight that the inherent uncertainty in parameters such as vessel travel times and port handling speeds further complicates the restoration of schedule reliability, as even minor operational delays can be amplified during large-scale systemic shocks.

Ports, as essential multimodal nodes in maritime supply chains, are inherently vulnerable to disruptions, both natural and human-driven (Notteboom et al., 2021). These disruptions include natural disasters such as typhoons, earthquakes, and floods, as well as labour strikes, cyberattacks, pandemics, and geopolitical tensions. What makes such events particularly critical is that their effects rarely remain local: congestion, rerouting, and vessel delays rapidly propagate across interconnected shipping networks and global supply chains, amplifying costs and reliability risks (Notteboom et al., 2021). This high degree of interconnectivity explains why even a disruption at a single port can escalate into a wider shipping crisis, revealing the structural vulnerability of maritime transport networks. Lee and

Meng (2015) highlight that such disruptions necessitate immediate management strategies to prevent localized delays from cascading through the entire supply chain. Whether in liner services or industrial shipping (such as bulk and tankers), the stability of the global network relies on the ability of ports and operators to maintain cargo flow and minimize the impact of unforeseen events on subsequent operations.

Disruptions in maritime transport can be classified according to both their origin and their predictability. Tran et al. (2025) distinguish between natural causes, such as severe weather events, droughts, and earthquakes, and human-related causes, including accidents, labor actions, cyber incidents, and geopolitical shocks. Beyond origin-based classifications, recent disruptions such as the COVID-19 pandemic and the Ever Given blockage illustrate the highly uncertain and non-linear nature of extreme events in maritime transport. These cases demonstrate that disruptions are rarely isolated incidents, but instead generate cascading effects across shipping networks and global supply chains, often requiring systemic rather than localized responses (Notteboom et al., 2021; Tran et al., 2025).

This shift towards systemic resilience is further supported by Ksciuk et al. (2023), who argue that maritime optimization must move beyond deterministic models to incorporate inherent uncertainties, such as fuel price volatility and variable port times, into tactical and strategic planning. By acknowledging these uncertainties, stakeholders can better prepare for the secondary follow-up disruptions and policy-driven shocks identified by Evgenidis et al. (2021). Such large-scale shocks can trigger systemic adjustments and policy responses which, although intended to stabilize the sector, may further prolong recovery and amplify economic impacts far beyond the transport sector.

2.2 Typology Of Disruptions

Natural disasters represent a major source of disruption in maritime transport, particularly for ports located in coastal and riverine areas. Events such as typhoons, earthquakes, tsunamis, floods, and storm surges can interrupt port operations and generate cascading effects across maritime networks and global supply chains. Empirical evidence based on vessel tracking data shows that natural-disaster-related disruptions often affect multiple ports simultaneously (Verschuur et al., 2020), while their impacts are heavily dependent on the disruption magnitude and the structural characteristics of the port network (Verschuur et al., 2020; Achurra-Gonzalez et al., 2019).

Geopolitical conflicts and security threats can abruptly alter global shipping routes and port accessibility, functioning as real-time stress tests for liner shipping networks and revealing structural vulnerabilities in maritime transport systems (Notteboom et al., 2024; Notteboom et al., 2021). The Russia/Ukraine war triggered severe disruptions to Black Sea shipping, undermining the reliability of established maritime corridors and generating spillover effects on global commodity markets and supply chains, particularly for energy and agricultural products (UNCTAD, 2022; UNCTAD, 2023). More recently, the Red Sea crisis triggered by Houthi attacks in late 2023 forced major shipping alliances to reroute vessels via the Cape of

Good Hope, bypassing the Suez Canal in most of the cases (Yap & Yang, 2024). This large-scale rerouting increased sailing distances and transit times, leading to substantial reconfigurations of Asia/Europe service networks and shifts in port call patterns, with traffic concentrating increasingly in Western Mediterranean hubs while ports in the Eastern Mediterranean and Red Sea regions experienced reduced connectivity (Yap & Yang, 2024).

Economic disruptions, including global financial crises, commodity price volatility, and imbalances in container availability, can significantly affect shipping, and particularly liner shipping as the backbone of global trade. The 2008/2009 financial crisis led to a sharp contraction in global trade volumes, forcing shipping lines to reduce service frequency, idle vessels, and rationalize capacity across major trade routes (Notteboom et al., 2021). More recently, the COVID-19 pandemic generated severe mismatches between container supply and demand, resulting in widespread port congestion and delays across Asia, North America, and Europe.

Pandemic-related operational constraints at major ports further disrupted vessel schedules and container circulation, prolonging delivery times and destabilizing supply chains (Notteboom et al., 2021). These events illustrate how economic shocks tend to amplify pre-existing logistical rigidities and systemic demand-capacity mismatches, producing persistent impacts on network efficiency and service reliability.

Technological failures and cyberattacks can immobilize entire shipping lines within hours. The 2017 NotPetya cyberattack on A.P. Møller-Maersk disrupted its global operations, forcing the shutdown of port terminals and booking systems for several days and resulting in estimated losses of approximately USD 300 million (Columbia University Case Study, 2021). Such attacks not only affect cargo handling but also erode trust in carriers' ability to safeguard digital infrastructure. The increasing digitalisation of shipping networks makes maritime transport more vulnerable to cyber risks, highlighting the need for robust contingency planning, network segmentation, and redundant recovery systems to ensure operational continuity during disruptions.

Beyond digital vulnerabilities, physical incidents at critical maritime chokepoints can abruptly halt global trade flows, generating immediate and far-reaching repercussions for maritime networks and global supply chains. The most notable recent example is the 2021 blockage of the Suez Canal by the 'Ever Given', which curtailed global trade by an estimated 0.2% - 0.4% per annum. This event created a backlog of 422 ships waiting for passage and severely disrupted global maritime supply chains, affecting the carriage of USD 51.1 billion worth of goods for the major shipping alliances alone (Tran et al., 2025). This incident illustrates how a single accident at a strategic chokepoint can propagate disruptions far beyond the immediate location, affecting multiple shipping segments and global trade flows.

Labor disputes remain a persistent and often predictable source of disruption in maritime transport. Strikes and industrial actions at ports can significantly reduce handling capacity, delay vessel operations, and trigger cargo diversion to alternative ports, with lasting effects on port competitiveness and network configuration. Unlike natural disasters, labour-related disruptions are often prolonged by negotiation deadlocks, increasing uncertainty for carriers and cargo owners and amplifying supply chain inefficiencies (Gu & Liu, 2025; Notteboom et al., 2021).

While the above sections treat disruptions as distinct categories, real-world crises often involve multiple dimensions simultaneously. Major disruption events frequently combine natural hazards, technological failures, and operational breakdowns, creating compound shocks that propagate across maritime networks and supply chains. Such multidimensional disruptions tend to be more persistent and difficult to manage, as recovery efforts must address several interrelated sources of vulnerability at the same time (Gu & Liu, 2025; Notteboom et al., 2021).

The 2011 Great East Japan Earthquake represents a highly complex disruption with prolonged operational impacts on maritime transport systems. The earthquake and subsequent tsunami caused extensive damage to port infrastructure and severely constrained maritime operations across eastern Japan, resulting in prolonged and phased disruptions during the initial months following the disaster. In response, transport and logistics systems were reorganized at the national level, with an emphasis on redundancy and the use of alternative routes and facilities to support the gradual restoration of logistics and economic activity, a process that remained ongoing years after the initial event (MLIT, 2011,2014; OECD, 2013).

The disruption extended beyond ports and shipping services, spilling over into manufacturing supply chains and industrial production systems. Prolonged interruptions to maritime connectivity constrained the availability of intermediate inputs, while uncertainty surrounding environmental and operational conditions delayed the restoration of regular shipping services. As a result, recovery to pre-disruption service levels required an extended period, highlighting how compound disruptions combining natural hazards with technological and environmental risks, can overwhelm even advanced maritime systems. These dynamics underscore the importance of resilience-oriented infrastructure planning and network diversification as long-term strategies to mitigate the impacts of complex maritime disruptions (Gu & Liu, 2025; UNCTAD, 2023).

2.3 Impacts Of Disruptions

Disruptions in shipping, and particularly in liner services, can significantly destabilize global supply chains, affecting both upstream suppliers and downstream consumers. Tran et al. (2025) highlight that the highly integrated nature of modern maritime networks means that a single port closure or the disruption of a critical chokepoint can trigger cascading delays across regions and continents. The 2021 Ever Given blockage of the Suez Canal illustrated this dynamic clearly, as the temporary closure of a key maritime passage led to vessel backlogs, rerouting decisions, and congestion across ports in Asia, Europe, and North America (Tran et al., 2025).

During the COVID-19 pandemic, port closures, quarantine measures, and operational restrictions, particularly in Asia, generated prolonged delays in the delivery of raw materials and intermediate goods, disrupting manufacturing schedules in Europe and North America for extended periods (Notteboom et al., 2021). Similar systemic effects were observed during the Panama Canal drought in 2023, when reduced water levels constrained transit capacity and forced carriers to reschedule voyages and delay cargo deliveries (UNCTAD, 2024). Collectively, such events expose the vulnerability of just-in-time logistics models and have prompted firms to reconsider inventory buffers, diversify sourcing strategies, and explore alternative transport corridors to enhance supply chain resilience.

During the Red Sea crisis, shipping alliances restructured port call patterns, leading to a relative decline in hubs located in the Eastern Mediterranean (e.g., Piraeus) and the Red Sea (e.g., Jeddah), which experienced substantial reductions in weekly port calls. In contrast, Western Mediterranean hubs including Algeciras and Tanger Med recorded noticeable gains in service share (Yap & Yang, 2024). Complementary evidence shows that feeder ports located closer to the Suez Canal suffered measurable losses in network connectivity, whereas ports near the Strait of Gibraltar strengthened their relative positions within the liner shipping network (Bedoya-Maya et al., 2025). Such reconfigurations tend to concentrate cargo flows through fewer and larger hubs, improving short-term operational efficiency but simultaneously increasing systemic vulnerability to future disruptions affecting these critical nodes.

According to Bedoya-Maya et al. (2025), the rerouting of Asia/Europe services via the Cape of Good Hope during the Red Sea crisis led to increases in generalized transport costs estimated between 3% and 13%, alongside significantly longer transit times. Yap & Yang (2024) further document that major alliances were forced to adjust their service networks, resulting in a marked reduction in weekly port calls in the Eastern Mediterranean and Red Sea regions. Similar dynamics were observed during the COVID-19 pandemic, when severe port congestion, equipment shortages, and vessel delays drove spot freight rates to historically high levels on major East-West routes (Notteboom et al., 2021; UNCTAD, 2023). Such sharp increases in transport costs directly erode shippers' profit margins and can accelerate strategic shifts toward nearshoring, regionalization, and supply chain diversification.

Bedoya-Maya et al. (2025) indicate that the rerouting of container services via the Cape of Good Hope during the Red Sea crisis was associated with a substantial spatial redistribution of shipping activity, which, combined with longer sailing distances, implies increased emissions and higher fuel consumption, reinforcing the environmental footprint of disrupted shipping networks (Tran et al., 2025). Beyond environmental implications, these effects translate into higher operational costs, particularly under increasingly stringent regulatory frameworks governing maritime emissions. As international and regional decarbonization policies tighten, prolonged rerouting and increased bunker consumption expose carriers to higher compliance costs, linking environmental impacts directly to the economic vulnerability of liner shipping under disruption scenarios.

Notteboom et al. (2021) observe that adaptive strategies such as slow steaming, capacity blanking, and alliance-based vessel sharing enhance network resilience under disruption, but also entail additional operational and cost pressures due to the reallocation of capacity in volatile market conditions. Similarly, Yap and Yang (2024) show that during the Red Sea crisis, shipping alliances adjusted vessel deployment and port rotations, in some cases deploying additional vessels within service loops to maintain service frequency despite longer transit times via the Cape of Good Hope. While these measures helped preserve service continuity, they simultaneously increased operating costs, illustrating how disruptions can translate into higher expenses even when schedule reliability is partially maintained.

Research on schedule recovery, the operational strategies adopted by carriers to restore service regularity after disruptions, highlights several adaptive mechanisms in liner shipping. Using AIS data, Zhang et al. (2023) show that port skipping is a widely applied strategy following disruptions, allowing shipping lines to recover schedules by bypassing lower-priority or more substitutable ports. Notteboom et al. (2021) further note that such recovery actions are often combined with broader network-level adjustments, including capacity blanking and alliance-based coordination, to stabilize services under volatile conditions. Evidence from recent disruption events, such as the Red Sea crisis and Suez Canal blockage, indicates that these operational responses help prevent network collapse but also generate trade-offs, as schedule recovery measures frequently increase operating costs and reduce overall system flexibility (Yap & Yang, 2024; Tran et al., 2025).

A further perspective on the impacts of disruptions relates to service reliability and timeliness in global supply chains. Empirical evidence from recent crises shows that delays in vessel schedules and port congestion significantly undermine on-time delivery performance. Notteboom et al. (2021) highlight that during large-scale disruptions such as COVID-19, delays propagated across maritime networks, reducing schedule reliability and increasing uncertainty for shippers. Similar effects were observed during the Red Sea crisis, where rerouting via the Cape of Good Hope extended transit times and further weakened delivery predictability for Asia-Europe trade lanes (Yap & Yang, 2024; Bedoya-Maya et al., 2025).

While freight rates, emissions, and port connectivity are among the most visible effects of maritime disruptions, end-to-end supply chain reliability often represents the most critical concern for shippers. Notteboom et al. (2021) emphasize that delays in vessel schedules and port operations propagate across interconnected supply chains, disrupting production planning, inventory management, and retail distribution. Evidence from recent crises shows that recovery from disruptions is uneven across regions: while UNCTAD (2023) highlights that developing regions face prolonged volatility compared to advanced economies, Bedoya-Maya et al. (2025) confirm this asymmetry within the European network, showing that major hubs recovered connectivity and operational stability faster than peripheral ports.

Overall, corporate responses to disruptions are multi-layered, combining tactical operational adjustments with broader strategic network reconfiguration. While such approaches can help restore service reliability in the short term, they frequently introduce additional cost and environmental pressures that shape long-term competitiveness in the shipping sector. Effective resilience therefore requires the integration of operational flexibility with strategic foresight, supported by technological capabilities and collaborative frameworks that enable firms to anticipate, absorb, and adapt to future shocks (Gu & Liu, 2025; Bednarski et al., 2025).

2.4 Resilience And Adaptation Strategies

One of the most immediate resilience strategies employed by liner shipping companies during disruptions is the use of alternative routing. The 2023/2024 Red Sea crisis exemplified this approach, with major carriers diverting vessels from the Suez Canal to the Cape of Good Hope in order to avoid conflict zones and heightened security risks (Yap & Yang, 2024). This rerouting substantially increased voyage distances and transit times, yet it enabled carriers to preserve service continuity on the Asia/Europe trade lane under conditions of elevated risk. Bedoya-Maya et al. (2025) estimate that such diversions resulted in transport chain cost increases ranging from approximately 3% to 13%. Crucially, the study highlights an uneven distribution of impacts: hub ports located near the Strait of Gibraltar experienced the smallest cost increases and reinforced connectivity, whereas ports in closer proximity to the Suez Canal suffered the most significant losses in competitiveness.

While the Cape Route provided a safer alternative with fewer security risks , it also introduced significant operational challenges. Longer voyages increased exposure to demand uncertainty, while extended transit times necessitated the deployment of more vessels to maintain a weekly service and resulted in higher fuel consumption (Hamdan et al., 2025). Bednarski et al. (2025) note that similar effects are often observed during geopolitical conflicts, where heightened security risks lead to increased voyage costs and service disruptions in affected regions. These examples illustrate that although alternative routing can mitigate immediate security threats, it often comes at the expense of operational efficiency, environmental performance, and schedule reliability.

Strategic alliances between carriers play a critical role in mitigating the impacts of disruptions by enabling operators to pool capacity and adjust port rotations more flexibly. Notteboom et al. (2021) highlight that vessel-sharing agreements enhance adaptive capacity by facilitating coordination and collective responses under disruption conditions. In the context of the Red Sea crisis, Yap & Yang (2024) document that major alliances actively restructured their networks, reallocating capacity and, in some cases, deploying additional vessels within service loops to accommodate longer transit times via the Cape Route and sustain service patterns. These adjustments helped absorb the shock of increased distances while preserving overall network integrity.

Regarding the geographical implications of these shifts, Yap & Yang (2024) provide evidence that Western Mediterranean hubs, such as Algeciras, strengthened their positions in the maritime network, recording gains in vessel connectivity, while Eastern Mediterranean hubs, including Piraeus, experienced notable declines in port calls. Bedoya-Maya et al. (2025) complement this finding by highlighting the cost dimension, noting that ports located near the Strait of Gibraltar gained a comparative advantage over those in proximity to the Suez Canal due to lower generalized transport costs for rerouted vessels. However, these alliance-driven adjustments are not without trade-offs, as coordinated strategies may redistribute congestion across the network and create tensions between collective alliance stability and individual carrier flexibility (Notteboom et al., 2021).

Technology-driven strategies are increasingly central to resilience planning in liner shipping, particularly as carriers face the combined pressures of operational reliability and environmental compliance. Notteboom et al. (2021) underline the growing role of digitalisation, including AIS-based vessel tracking, enhanced information sharing, and real-time monitoring of weather and operational risks, as key enablers of adaptive capacity in shipping networks. These technologies improve visibility across complex maritime supply chains and support more timely decision-making during disruptions, allowing carriers to anticipate operational risks and adjust routes, schedules, and capacity deployment more effectively under volatile conditions.

Furthermore, technology plays a crucial role in aligning resilience with sustainability objectives in maritime transport. The increasing integration of digital decision-support tools allows carriers to consider environmental performance alongside operational reliability when responding to disruptions. This development has become particularly relevant as regulatory frameworks such as the IMO’s Carbon Intensity Indicator (CII) and Energy Efficiency Existing Ship Index (EEXI) impose stricter constraints on vessel operations (UNCTAD, 2023). More broadly, the literature highlights a growing convergence of operational efficiency, environmental responsibility, and digitalisation, reflecting a structural shift in how the shipping industry approaches resilience under conditions of heightened regulatory and disruption-related pressure (Notteboom et al., 2021; Gu & Liu, 2025).

2.5 Synthesis And Knowledge Gaps

The literature reviewed demonstrates that disruptions in liner shipping are diverse in origin, magnitude, and duration. As summarized in Table 2.1, each disruption type carries specific operational and economic consequences, shaping the resilience strategies adopted by stakeholders. Despite this diversity, a recurring theme, highlighted by Notteboom et al. (2021) and Achurra-Gonzalez et al. (2019), is the high degree of structural interconnectedness, whereby localized disruptions propagate rapidly to generate global impacts.

Table 2.1 Overview of Disruptions, Impacts, and Adaptation Strategies

Disruption Type	Main Impacts	Key Adaptation Strategies
Natural disasters (typhoons, earthquakes, floods)	Port closures, cargo delays, infrastructure damage, supply chain bottlenecks	Rerouting to alternative ports, contingency berthing, pre-season scheduling buffers
Geopolitical & security events (wars, piracy, blockades)	Route blockages, increased voyage distance, cargo security risks, port hierarchy shifts	Rerouting (e.g., Cape Route), alliance capacity pooling, political risk monitoring
Economic & market shocks (financial crises, pandemics)	Demand collapse or surge, congestion, equipment imbalance, freight rate volatility	Blank sailings, service consolidation, flexible contract terms
Technological & cyber disruptions	Terminal shutdowns, booking system failures, cargo misrouting	IT redundancy, cyber resilience protocols, manual fallback operations
Maritime accidents (collisions, explosions, canal blockages)	Immediate service halt, vessel queues, cargo value loss	Port skipping, emergency towage, schedule recovery plans
Labour disputes & strikes	Reduced port productivity, prolonged delays, customer loss	Negotiation acceleration, temporary service diversion, multi-port routing

Source: Author, based on literature review

While existing research provides valuable insights, several critical gaps remain. First, most studies tend to examine disruption events in isolation. For instance, Tran et al. (2025) focus exclusively on the Suez blockage, while Yap & Yang (2024) analyze the Red Sea crisis. Comparative assessments across different categories of disruptions and geographical contexts remain limited, with Notteboom et al. (2021) being a notable exception in comparing pandemic versus financial shocks. Second, there is insufficient integration between quantitative network metrics and cost-oriented analyses. At the same time Bedoya-Maya et al. (2025) successfully link rerouting to generalized costs, broader frameworks that simultaneously evaluate port connectivity changes (as per Yap & Yang, 2024) and their direct economic implications on supply chains are often lacking. Third, although the role of strategic alliances is acknowledged as critical for short-term recovery (Notteboom et al., 2021), their contribution to long-term resilience building under conditions of simultaneous, multi-region disruptions remains underexplored.

Finally, explicitly linking environmental impact assessments to disruption management strategies remains a developing field. Despite the regulatory pressures noted by UNCTAD (2023), few studies, apart from Asghari et al. (2023), integrate emissions modeling directly into disruption recovery algorithms. Addressing these gaps requires an empirical approach that combines AIS-based vessel tracking, port connectivity analysis, and cost simulations.

2.6 Tools And Metrics For Assessing Disruptions

At the macro level, widely used indicators such as UNCTAD's maritime transport statistics provide an important contextual framework for understanding logistics performance. UNCTAD (2023) data reveals that while global seaborne trade volumes often remain resilient in aggregate, operational indicators such as port calls, vessel turnaround times, and schedule reliability deteriorated sharply during recent shocks like the COVID-19 pandemic and the Red Sea crisis.

However, these macro-level metrics are inherently aggregated, limiting their ability to capture the localized and time-specific operational effects of individual disruption events. To overcome these limitations, the literature increasingly relies on Automatic Identification System (AIS) data to assess disruptions at a finer spatial and temporal scale. Verschuur et al. (2020) demonstrated the utility of AIS in quantifying the duration and propagation of port disruptions following natural disasters, while Zhang et al. (2023) utilized AIS trajectories to precisely identify strategic behaviors such as port skipping and schedule recovery maneuvers.

By enabling the observation of granular changes in vessel routing and port-call decisions at the event level, AIS data allows for the identification of strategic operational responses to disruptions, such as port skipping and schedule recovery (Zhang et al., 2023). Consequently, a data-driven approach based on AIS tracking offers a more robust methodological foundation for evaluating the complex dynamics of maritime disruptions compared to traditional static metrics.

3. Methodology

In this chapter I outline the methodological framework I developed to examine how different types of disruptions affect vessel activity, as captured through daily distinct vessel movements derived from AIS data, across the global maritime transportation system. I combine quantitative techniques based on AIS data processing with qualitative evidence obtained from authoritative institutional and industry sources, which I used for contextualization and interpretation of the observed traffic patterns, allowing for a comprehensive assessment of disruption dynamics. I apply a unified analytical procedure across all six disruption categories included in my study, ensuring consistency and comparability while allowing for event-specific adaptations in geographical delineation and temporal comparison when required. I have structured into sections covering my research design, analytical techniques, data collection and processing procedures, methodological limitations, and ethical considerations.

While the literature review discusses large-scale systemic disruptions such as the Suez Canal blockage and the Red Sea crisis to illustrate the structural vulnerability of liner shipping networks, the empirical analysis of this thesis focuses on observable disruption events in the USA and Denmark, which serve as controlled regional case studies for quantifying operational traffic responses through AIS-based measurement.

Table 3.1. Overview of Disruptions, Study Areas and Time Windows

Disruption type	Region / focal ports	AIS dates to download (pre peak post)	Event (short description & link)
Natural disasters A	US Gulf Port of Houston & approaches (bulk, tanker, chemical terminals)	**Pre:** 15-08-2017 **Peak:** 27-08-2017 **Post:** 10-09-2017	**Hurricane Harvey** Category-4 hurricane; Houston Ship Channel and ports along the Texas coast closed for several days due to flooding and safety restrictions, causing queues of vessels offshore.
Natural disasters B	Danish North Sea / Skagerrak & Kattegat West coast + approaches to major Danish ports	**Pre:** 20-01-2022 **Peak:** 29-01-2022 **Post:** 10-02-2022	**Storm Malik (Jan 2022)** Severe windstorm over Denmark and North Sea causing very rough seas, ferry cancellations and disruptions to coastal traffic.
Geopolitical & security events A	Baltic Sea Bornholm area (Danish & Swedish EEZ)	**Pre:** 15-09-2022 **Peak:** 26-09-2022 **Post:** 10-10-2022	**Nord Stream pipeline explosions** Four leaks/explosions on Nord Stream 1 & 2 near Bornholm; safety/exclusion zones established, intensive naval presence and routing changes around the incident area.
Geopolitical & security events B	US Gulf LNG & crude export terminals (Sabine Pass, Corpus Christi, etc.)	**Pre:** 01-02-2022 **Peak:** 15-03-2022 **Post:** 01-11-2022	**Russia Ukraine war & energy sanctions** After the 24-02-2022 invasion, European demand for US LNG and non-Russian crude surged; strong increase in tanker/LNG exports from US Gulf to Europe (longer routes, different destination mix).
Economic & market shocks A	Denmark main container & ferry ports (Aarhus, Copenhagen/Malmö, etc.)	**Pre:** 01-03-2020 **Peak:** 01-04-2020 **Post:** 01-07-2020	**COVID-19 first wave Denmark** National lockdown announced 11-03-2020; reduction of passenger/ferry traffic and disturbances in intra-European trade flows.

Economic & market shocks B	US coastal ports (focus e.g. New York-New Jersey, LA/Long Beach, Houston)	**Pre:** 01-03-2020 **Peak:** 01-04-2020 **Post:** 01-07-2020	**COVID-19 first wave US** National emergency declared 13-03-2020; collapse of cruise/passenger movements and initial slowdown in some cargo segments before later demand surge.
Technological & cyber disruptions A	US East Coast APM Terminals (Port Elizabeth NJ, LA-LB, etc.)	**Pre:** 20-06-2017 **Peak:** 27-06-2017 **Post:** 10-07-2017	**NotPetya cyber-attack (Maersk / APMT)** Ransomware attack on 27-06-2017 shut down Maersk IT systems and APM Terminals operations at several ports, temporarily halting or slowing vessel operations.
Technological & cyber disruptions B	North European network incl. Scandinavian terminals (e.g., Gothenburg, Aarhus)	**Pre:** 20-06-2017 **Peak:** 27-06-2017 **Post:** 10-07-2017	Same **NotPetya** event, but analysed from the perspective of North Europe / Scandinavia (interaction with ongoing labour dispute at Gothenburg).
Maritime accidents A	Gulf of Mexico - offshore fields & approaches to US Gulf ports	**Pre:** 10-04-2010 **Peak:** 22-04-2010 **Post:** 01-06-2010	**Deepwater Horizon explosion & oil spill** 20-04-2010 blowout on BP’s Macondo well; safety zones and drilling moratorium affected offshore supply and some tanker/shuttle traffic in the Gulf.
Maritime accidents B	Global liner network, measured at arrival ports (e.g., US East Coast + North Europe incl. Denmark)	**Pre:** 10-03-2021 **Peak:** 27-03-2021 **Post:** 15-04-2021	**Ever Given Suez Canal blockage** Ultra-large container ships grounded 23-03-2021 blocking Suez until 29-03-2021; caused queues and later “bunching” of liner arrivals in Europe and US.
Labour disputes & strikes A	US West Coast - Los Angeles/Long Beach and other WC ports	**Pre:** 01-10-2014 **Peak:** 01-02-2015 **Post:** 01-06-2015	**ILWU PMA labour dispute 2014-15** Contract negotiations led to slowdowns and congestion at West Coast container ports;

			vessel queues and long port stays.
Labour disputes & strikes B	Nationwide labour strikes in Denmark (2008 collective bargaining conflict)	**Pre:** 01-03-2008 **Peak:** 24-04-2008 **Post:** 31-05-2008	**Nationwide labour strikes in Denmark** in April 2008 disrupted several sectors, including transport and port logistics, temporarily affecting maritime operations across the country.

Author. *Table 3.1 summarizes the disruption events analyzed in this study, including their geographical scope and event-specific temporal windows. While a common pre/peak/post structure is applied across all cases, the length of the observation windows and the use of year-before or year-after reference periods are adapted when necessary to account for seasonal effects or longer-term structural changes. This ensures methodological consistency while preserving sensitivity to the specific characteristics of each disruption.*

3.1 Research Design

I adopt an event-based analytical framework to examine disruptions affecting maritime traffic across multiple typologies.Unlike traditional case study approaches, I employ a unified analytical procedure applied consistently to six distinct categories of disruptions: natural disasters, geopolitical and security events, economic and market shocks, technological and cyber disruptions, maritime accidents and labor disputes. This structure ensures comparability across events of different scale and nature, addressing the gap identified in the literature regarding cross-disruption empirical studies in marine shipping networks.

I follow a quantitative, AIS-driven methodology, reflecting my need to observe disruptions as they manifest in real vessel behavior rather than solely through secondary indicators such as freight rates or carrier capacity announcements. AIS data allow the extraction of objective, high-resolution signals of maritime activity, including vessel presence, movement patterns and routing behavior. By analyzing each disruption through three temporal windows (pre-event, peak-event and post-event), the study captures both the immediate and residual effects of shocks, enabling a dynamic assessment of resilience and recovery. Comparability across disruption types is achieved through the use of standardized vessel-based indicators and normalized impact measures, which allow changes in traffic intensity to be assessed on a relative basis across events of different scale, duration and geographical extent.

At the same time, the research design preserves the contextual depth of case-based reasoning. Each disruption is studied within its specific geographical setting through the definition of spatial boundaries (bounding boxes) that correspond to the physical area affected by the event. This combination of spatial filtering, temporal segmentation and behavioral metrics provides a structured approach consistent with contemporary methodologies in maritime analytics, while allowing the findings to be interpreted within their operational and geographical context. Overall, my design supports a comparative understanding of how different types of disruptions alter vessel traffic patterns, contributing to a more holistic assessment of vulnerability in liner shipping systems.

3.2 Analysis

3.2.1 Quantitative Analysis

I base the quantitative analysis on the systematic processing of Automatic Identification System (AIS) data in order to measure how disruption events affect vessel presence within defined geographical areas. Rather than focusing on indirect indicators such as freight rates or port statistics, I rely on observed vessel presence as recorded through AIS transmissions, allowing me to examine disruption effects directly at the operational level.

For each disruption event, I temporally segment the AIS dataset into three discrete observation windows: a pre-event phase, a peak-event phase and a post-event phase. I define these windows using event timelines established from official institutional sources and verified news reports. This temporal segmentation enables me to compare vessel presence under baseline conditions, during the disruption, and throughout the initial recovery period.

Following temporal segmentation, I apply spatial filtering to isolate AIS observations within the geographic area affected by each event. I define rectangular bounding boxes to represent the operational perimeter of interest, adapting their size and location to the spatial characteristics of each disruption. I examine large-scale events, such as hurricanes, through broader regional boundaries, whereas I analyze localized incidents within more concentrated spatial frames.

Within each temporally and spatially filtered dataset, I extract and aggregate unique vessel identifiers (MMSI) on a daily basis. Daily distinct MMSI counts constitute my primary quantitative indicator of vessel presence within the affected area. Changes in this indicator allow me to capture variations in traffic intensity associated with disruption, withdrawal, congestion or delayed clearance of vessels.

To evaluate the magnitude of disruption effects, I calculate a normalized impact measure based on deviations from a defined baseline traffic level. I define the baseline as the median daily distinct MMSI count during the pre-event window of the same year. In cases where I expect strong seasonal variation or broader structural shifts, I use the median of the equivalent calendar period of the previous year instead to ensure comparability and avoid seasonal bias.

Where the nature of the disruption primarily affects specific maritime sectors, I selectively disaggregate the analysis by vessel type. For example, I examine container vessels separately in liner shipping disruptions, while I consider tanker or LNG vessels in energy-related events. This targeted disaggregation allows me to identify sector-specific impacts without imposing vessel-type filtering uniformly across all cases.

In certain disruptions, particularly weather-related events, I recognize that stable or increasing vessel presence during or immediately after the event does not indicate uninterrupted operations. Instead, I interpret such patterns as reflecting vessels remaining in port, anchorage, or delayed arrivals accumulating within the study area. I capture these dynamics quantitatively through deviations in vessel presence relative to pre-event baseline conditions.

I implement all quantitative processing steps through custom Python scripts developed for this study. My workflow automates temporal segmentation, spatial filtering and the extraction and aggregation of unique MMSI identifiers, ensuring methodological consistency, reproducibility and comparability across all disruption events analyzed.

3.2.2 Qualitative Analysis

The qualitative dimension of the methodology complements the AIS-based quantitative analysis by providing contextual depth and interpretive grounding for each disruption event. Rather than generating independent qualitative indicators, I use this component to interpret observed changes in vessel presence patterns identified in the AIS data. I draw qualitative information from authoritative institutional reports, industry publications and reputable international news organizations, ensuring that the quantitative findings are situated within an accurately defined real-world operational framework rather than interpreted in isolation.

Official documentation constitutes the core of the qualitative evidence base. Meteorological agencies such as NOAA provide verified accounts of the onset, intensity and duration of extreme weather events, while maritime authorities, including the Danish Maritime Authority, issue navigational warnings, safety notices and exclusion zone announcements relevant to security incidents. I use corporate communications from affected operators in cases involving cyber disruptions or labor disputes to document operational shutdowns, system outages and contingency measures. I use these sources to establish and validate event timelines and to support the definition of the temporal windows applied in the AIS-based quantitative analysis.

Academic literature and sectoral analyses published by organizations such as UNCTAD and the OECD, together with reporting from reputable news agencies including Reuters and the BBC, provide additional contextual insight into broader structural and operational conditions within the maritime system. I primarily apply the qualitative analysis during the interpretation of quantitative results and impact diagrams and link observed increases, decreases or accumulations in vessel presence to documented operational circumstances such as port closures, congestion, delayed arrivals or traffic avoidance. In this way, the qualitative component supports a coherent and transparent interpretation of the quantitative findings without implying formal causal inference.

3.3 Data Collection

The data collection process was designed to assemble a reliable and event-focused dataset capable of capturing vessel presence across different segments of the maritime transportation system. Automatic Identification System (AIS) data constitute the primary source for the quantitative analysis, while I use supplementary qualitative information from institutional, meteorological and industry sources to establish the factual and operational context of each disruption event. This combined approach ensures that the dataset is both empirically robust and contextually grounded, in line with the event-based analytical framework adopted in this study.

I obtain AIS data from official national providers, including the U.S. Marine Cadastre for United States coastal regions and the Danish Maritime Authority for waters surrounding Denmark. These platforms supply raw positional AIS records containing time-stamped geographic coordinates and unique vessel identifiers (MMSI). I query the AIS archives to retrieve all vessel transmissions falling within the predefined temporal windows corresponding to the pre-event, peak-event and post-event phases of each disruption, as defined using verified institutional reports and reputable news sources.

I perform geographical filtering through the application of rectangular bounding boxes delineating the maritime areas directly affected by each disruption. The spatial extent of these boundaries varies according to event characteristics, with large-scale natural phenomena requiring broader regional coverage and localized incidents examined within more narrowly defined geographic frames. As AIS datasets are sourced from different national providers, variations in data structure and field naming are present across regions. I therefore apply data preprocessing procedures to harmonize timestamps, vessel identifiers and relevant attributes prior to analysis, ensuring consistency across all cases.

To complement the AIS dataset, I collect additional qualitative information from authoritative organizations documenting each disruption event. Meteorological agencies provide verified accounts of environmental disruptions, while maritime authorities issue navigational warnings and operational updates following safety incidents or infrastructure failures. I review official statements from port operators and shipping companies in cases involving cyber disruptions or labor disputes. Academic publications, institutional reports from organizations such as UNCTAD and the OECD, and reporting from reputable international news agencies support the accurate definition of event timelines and spatial boundaries. These sources also inform the interpretation of observed patterns in vessel presence and concentration identified in the quantitative analysis.patterns in vessel presence and concentration identified in the quantitative analysis.

3.4 Research Limitations

The methodological approach adopted in this study is subject to several limitations arising from the characteristics of AIS data. AIS transmissions may contain gaps due to signal loss, equipment malfunction or adverse operating conditions, particularly in areas with dense traffic or severe weather. Such irregularities may affect the completeness of vessel presence records within specific geographical areas and lead to an underestimation of the number of vessels present during certain periods. While I apply data preprocessing and aggregation procedures to mitigate these effects, this limitation is inherent to AIS-based analyses and should be taken into account when interpreting the quantitative results.

Another limitation concerns the absence of detailed vessel metadata in some AIS records, such as ship type or draught information, which restricts the ability to disaggregate vessel presence by maritime sector in certain cases. As a result, I can conduct sector-specific analyses only when relevant vessel attributes are consistently available in the AIS data. In addition, military and government vessels frequently operate with AIS switched off for security reasons, and therefore their presence cannot be captured in the quantitative analysis, even when they play an active role in managing or responding to a disruption. This limitation is particularly relevant for security-related events such as the Nord Stream incident.

Variability in data availability across geographical regions also affects comparability. The density and resolution of AIS coverage differ between national providers, implying that analyses of the United States coastal regions and the Danish maritime zone may exhibit inherent asymmetries. Furthermore, the bounding box method, while necessary for isolating affected areas, simplifies the spatial complexity of some disruptions whose impacts may extend beyond the defined geographic perimeter, potentially leading to partial capture of spillover effects.

Finally, the interpretation of AIS-derived vessel presence patterns relies on qualitative sources that I use for contextualization and validation. The temporal boundaries of each event, as well as the operational conditions used to interpret observed changes in vessel presence, depend on the accuracy and timing of external documentation. Any inaccuracies or reporting delays in official or news sources may therefore influence the definition of the analytical windows applied in the study. Despite these limitations, the integrated methodological approach provides a robust, transparent and replicable framework for analyzing maritime disruption dynamics.

3.5 Ethical Considerations

The ethical considerations of this study relate primarily to the responsible use of AIS data and the integrity of the analytical process. AIS transmissions do not contain personal information and identify vessels only through numerical codes such as MMSI, which do not reveal the identity of shipowners, crew members or commercial counterparts. I use the data exclusively in aggregated form for research purposes, without any attempt to link AIS records to individuals or commercially sensitive entities, ensuring that the analysis adheres to accepted data protection and research ethics principles.

I adhere to the usage terms established by the national authorities providing the AIS data, including the U.S. Marine Cadastre and the Danish Maritime Authority. I employ the data exclusively for academic and non-commercial purposes. While I apply standard methodological processing steps such as filtering, aggregation and normalization to support the analysis, I make no attempt to alter, de-anonymize or repurpose the data beyond their intended public-use format. I ensure that the interpretation of results remains strictly analytical and does not imply operational judgments about individual vessels, operators or shipping companies.

Finally, I integrate qualitative sources with attention to accuracy, transparency and proper attribution. I use information from institutional reports, meteorological services and reputable news agencies solely to establish the factual context and timelines of each disruption, without altering, amplifying or selectively interpreting documented events. In cases involving geopolitical or security-sensitive incidents, the analysis maintains analytical neutrality and does not attribute responsibility or advance normative or political interpretations. By maintaining transparency in source selection and interpretation, the study upholds the ethical standards expected in maritime research.

4. Results

This chapter presents the empirical findings of the study, examining how different types of disruptions affect vessel traffic patterns across selected maritime regions. Building upon the methodological framework introduced in Chapter 3, I evaluate twelve case studies grouped into six disruption categories: natural disasters, geopolitical and security events, economic and market shocks, technological and cyber incidents, maritime accidents, and labour disputes.

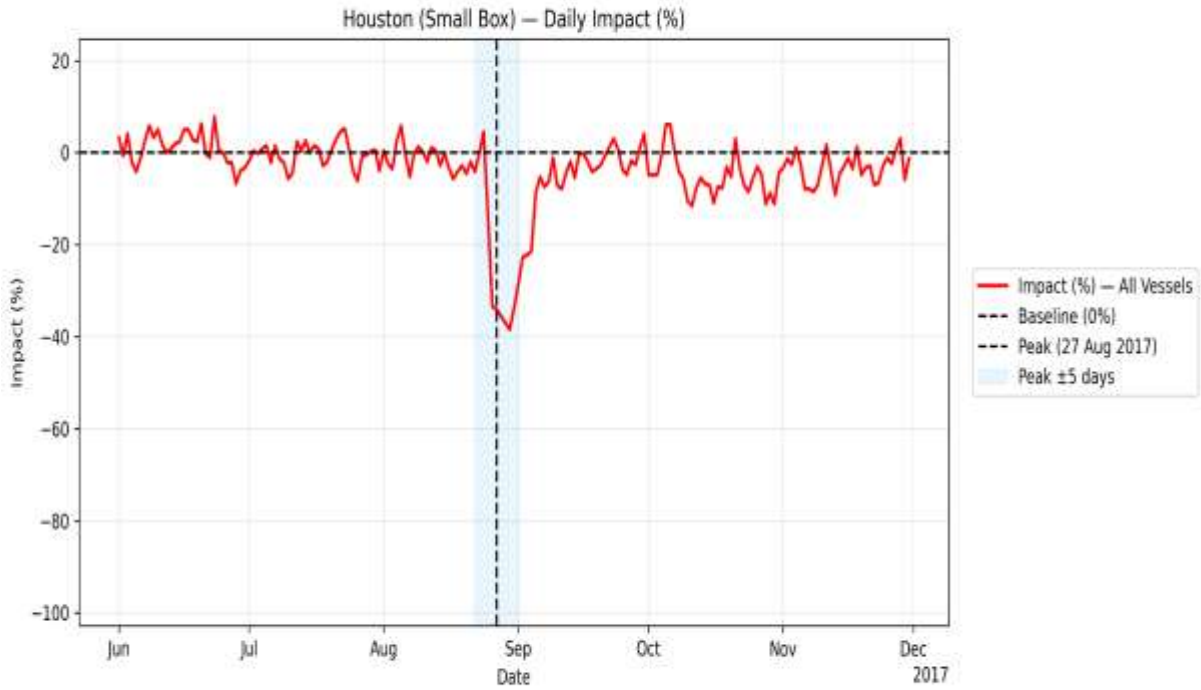
For each case, I assess vessel traffic dynamics using daily counts of distinct MMSI within defined spatial boundaries. The objective is to identify deviations from baseline activity, measure the intensity and duration of disruptions, and evaluate recovery trajectories. Where necessary, I incorporate equivalent calendar periods from adjacent years to control for seasonal variation and strengthen the robustness of the interpretation.

I present the results by disruption category, allowing both case-specific analysis and cross-event comparison. This structure facilitates the identification of recurring impact patterns and distinguishes between structural network disruptions, temporary operational volatility, congestion accumulation, demand-driven shocks, and rerouting effects within the global maritime system.

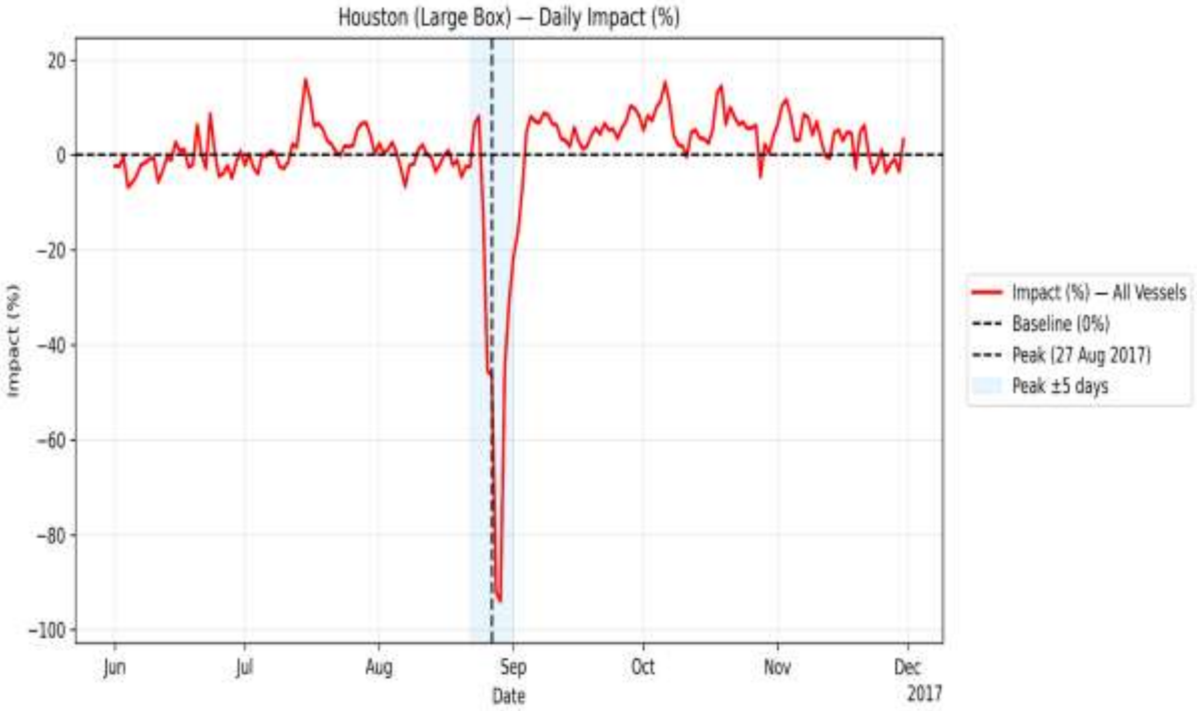
4.1 Natural Disruption USA

The analysis of the Hurricane Harvey event-year data reveals a clear deviation from normal maritime traffic conditions in the Port of Houston area. Prior to the event, vessel activity appears relatively stable, with traffic levels fluctuating within a narrow range around the baseline. The statistical indicators confirm that vessel presence in the study area followes a consistent pattern, suggesting a well-functioning operational environment with limited irregular fluctuations in daily maritime activity.

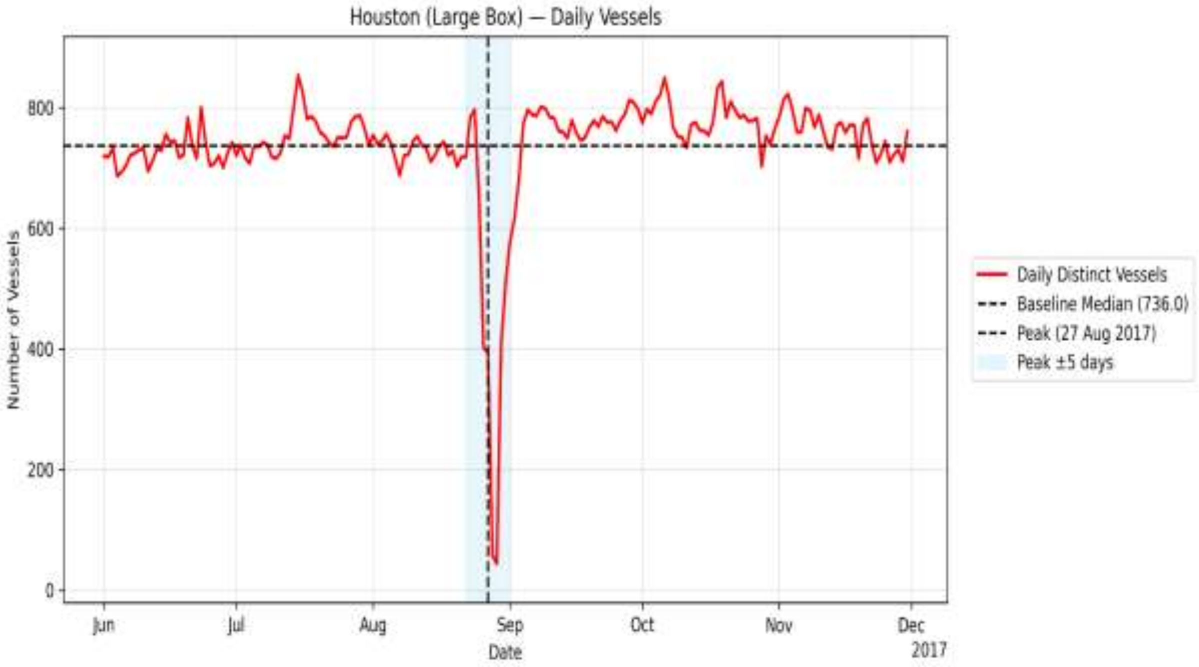
Hurricane Harvey made landfall on the Texas Gulf Coast in late August 2017 as a powerful tropical cyclone, causing extensive flooding and forcing the closure of the Houston Ship Channel. As a result, port operations were temporarily suspended, interrupting vessel movements and affecting maritime logistics in the wider Gulf region. Previous empirical studies using AIS vessel tracking data confirm that the hurricane led to a substantial disruption in port activity and vessel calls in the Houston area.



The event-year distribution of vessel counts reflects a pronounced break from the baseline traffic pattern during the peak of the hurricane. Vessel activity drops abruptly during the event window, indicating a sudden interruption in maritime operations. This sharp decline is not consistent with normal traffic variability but instead reflects a direct operational disruption caused by the severe weather conditions and the temporary shutdown of port infrastructure.

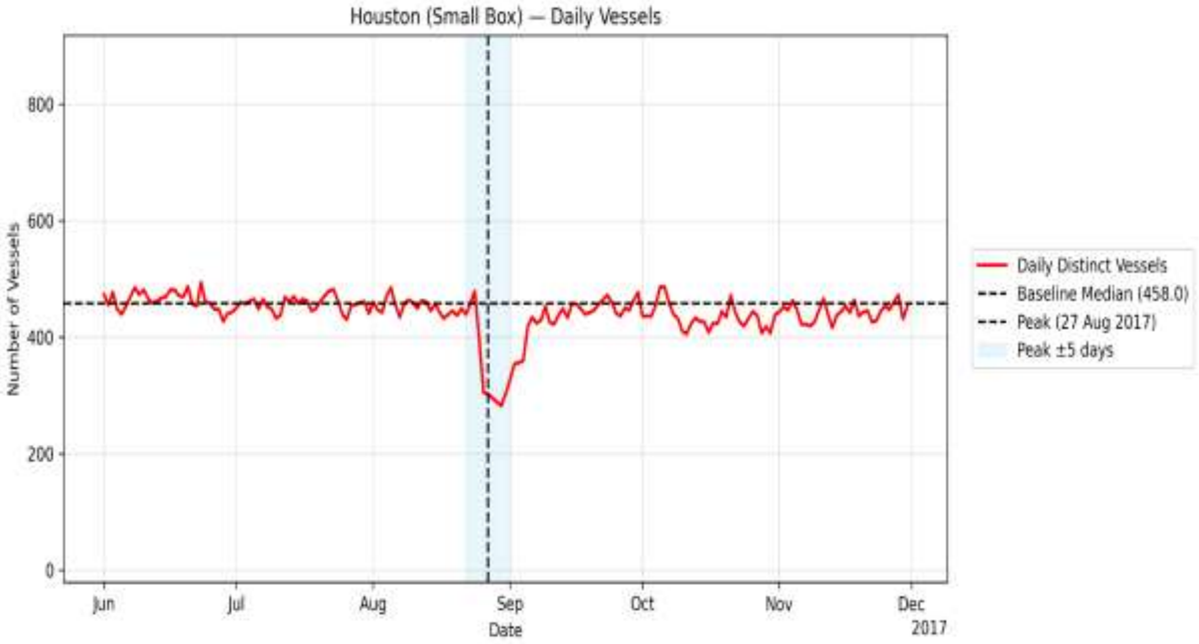


Following the peak of the event, vessel traffic gradually returns toward its pre-event levels as port operations are restored and navigational conditions improve. The recovery pattern suggests that the disruption was intense but relatively short-lived, with maritime traffic progressively stabilizing after the reopening of the channel and the resumption of normal port procedures.



The comparison between the different spatial observation areas further highlights the nature of the disruption. While the broader maritime area surrounding the port experiences a substantial reduction in vessel movements during the peak of the event, activity within the inner port area declines to a lesser extent. This spatial pattern suggests that although inbound and outbound traffic was significantly restricted, a portion of vessels remained within the port's anchorage or operational zones during the disruption period.

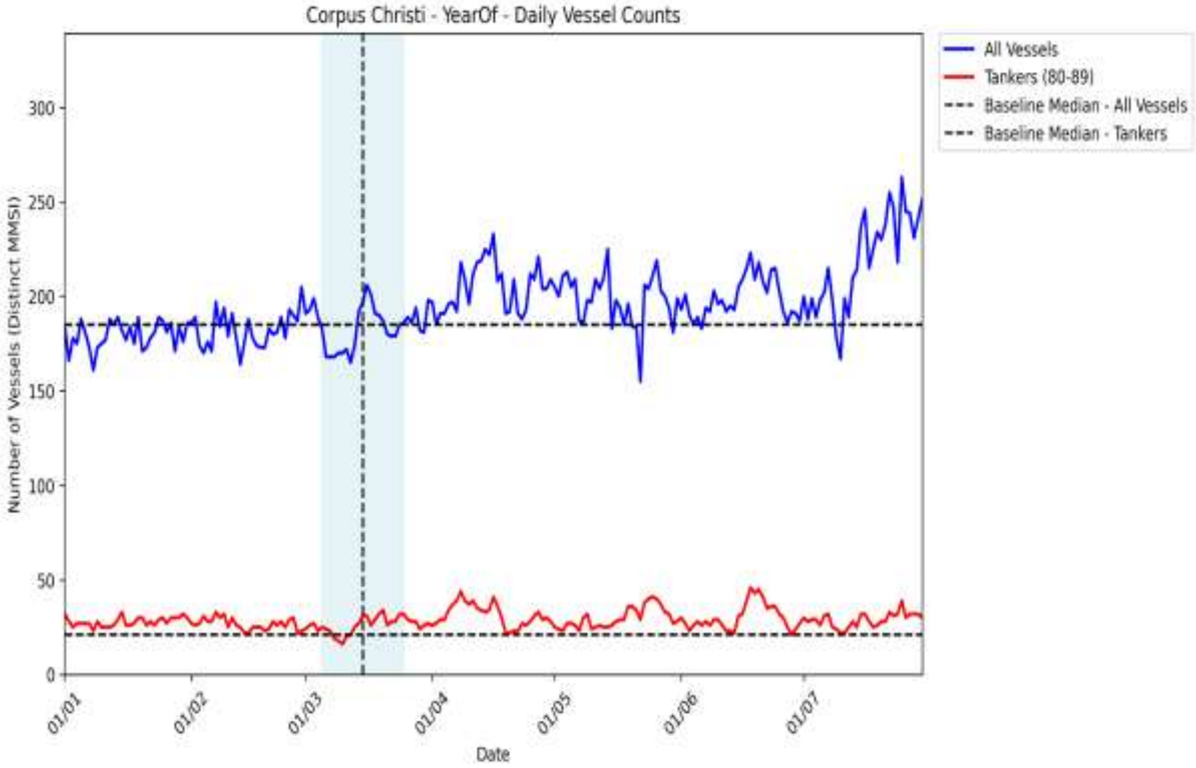
Overall, the observed patterns indicate that Hurricane Harvey generated a system-wide disruption in maritime activity in the Port of Houston region. The event reflects a temporary but severe supply-side shock caused by the physical interruption of port accessibility and infrastructure operations. Vessel traffic contracted sharply during the peak of the hurricane and gradually recovered once operational conditions were restored.



In disruption classification terms, the event can be characterized as a structural operational disruption triggered by an external natural hazard. Rather than reflecting changes in demand or internal port congestion, the disruption primarily resulted from the temporary shutdown of port access and the suspension of normal maritime operations due to extreme weather conditions.

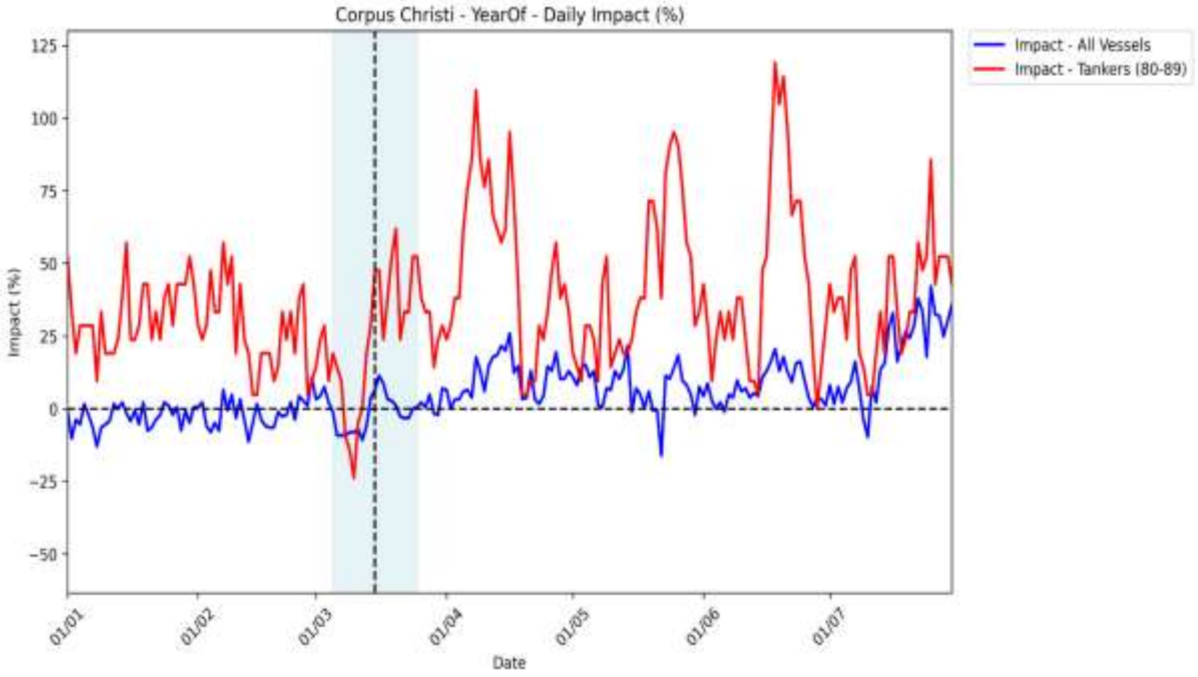
4.2 Geopolitical Shock and Port Traffic Realignment USA

The full-scale invasion of Ukraine by Russia in early 2022 and the subsequent imposition of Western sanctions on Russian energy exports significantly altered global energy trade patterns. As European markets attempted to reduce their dependence on Russian oil and natural gas supplies, alternative energy sources became increasingly important. In this context, the United States emerged as a key supplier of crude oil and liquefied natural gas, leading to a reconfiguration of international energy flows and maritime transport routes (Reuters, 2022). Within this broader geopolitical framework, changes in maritime traffic patterns can be observed in important export locations along the U.S. Gulf Coast, including Sabine Pass and Corpus Christi.



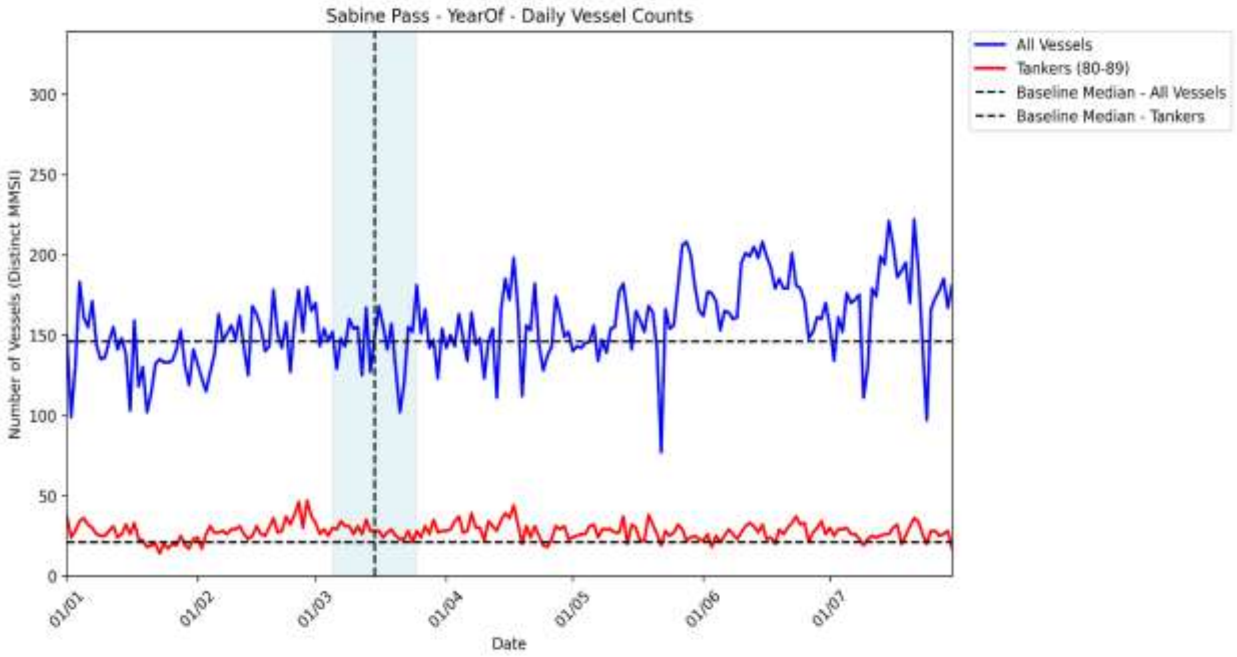
During the period preceding the disruption, vessel traffic in the examined ports appears relatively stable. In the diagram of the year before the event, the curve representing all vessels fluctuates around a consistent level without strong upward or downward movements. A similar pattern is observed for the tanker curve, which displays normal operational variability but no persistent change in activity levels. The impact diagram for the same period further supports this interpretation, as both the all-vessels impact curve and the tanker impact curve oscillate around the baseline, indicating that port activity remained within the expected operational range before the geopolitical developments.

The situation begins to evolve during the year of the event. In the diagram corresponding to the year of the disruption, the curve representing all vessels shows a gradual tendency toward higher levels compared with the pre-event period. Although daily fluctuations remain present, the overall trajectory suggests a moderate increase in maritime activity. The tanker curve displays a similar behavior, with several periods in which vessel counts appear above the baseline reference level. This pattern is also reflected in the impact diagram of the event year, where the tanker impact curve frequently moves above the neutral reference line, while the all-vessels impact curve also shows more frequent positive deviations compared with the previous year.

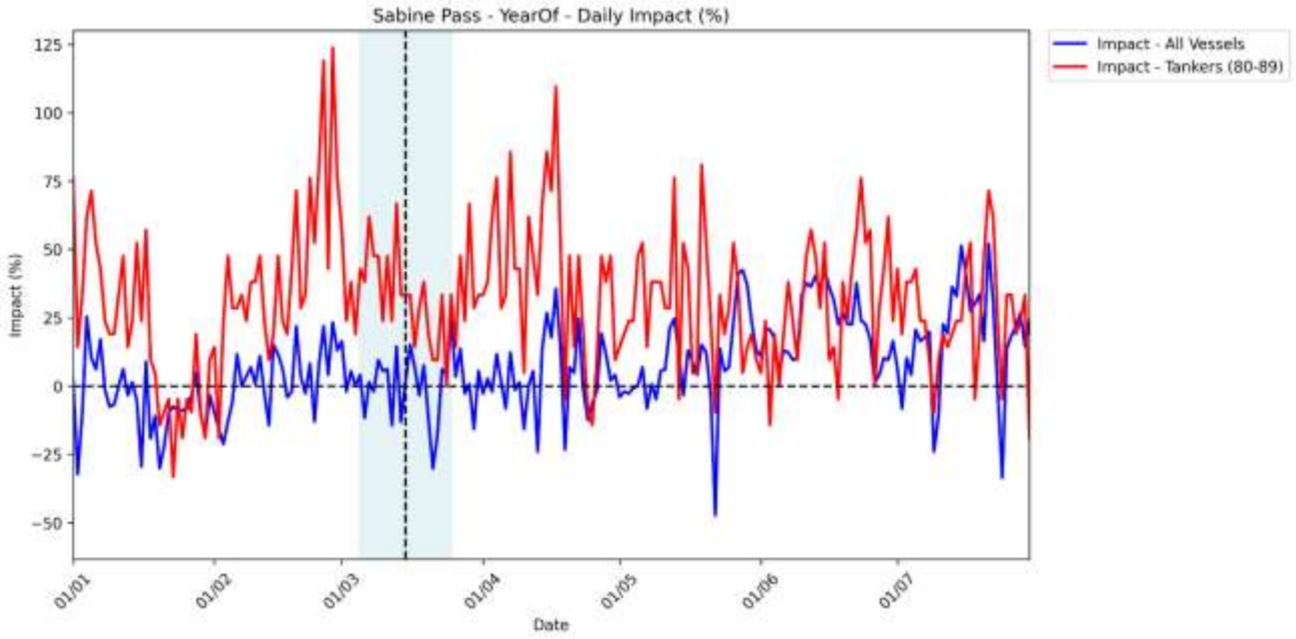


The period following the disruption provides further insight into the evolution of maritime traffic patterns. In the diagram of the year after the event, the curve representing all vessels remains generally above the level observed in the earlier period. The tanker curve also maintains higher values than those seen before the disruption, suggesting that the increased activity did not disappear once the immediate geopolitical shock had passed. In the corresponding impact diagram, the curves continue to display predominantly positive values, indicating that vessel traffic frequently exceeded the baseline conditions established before the event.

When the two ports are examined together, a similar pattern becomes visible. In both Sabine Pass and Corpus Christi, the curves associated with tanker traffic tend to display more pronounced responses than the curves representing the total number of vessels. This difference is consistent with the role of these ports as key energy export hubs, where tanker traffic is directly linked to global oil and liquefied natural gas flows. As international energy trade patterns shifted following the geopolitical developments in Eastern Europe, these ports appear to have absorbed part of the increased demand for alternative energy supplies.

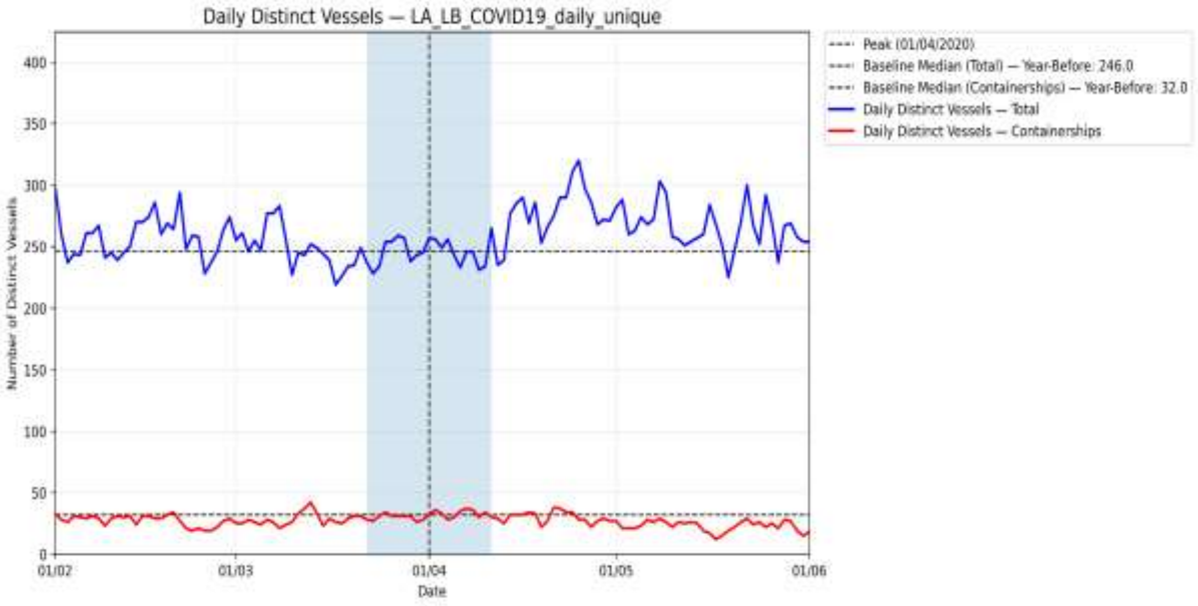


Overall, the graphical evidence suggests that the geopolitical developments associated with the war in Ukraine coincided with a noticeable adjustment in maritime traffic patterns at the examined U.S. Gulf ports. While daily fluctuations remain present, the curves observed in the diagrams indicate a general movement toward higher levels of vessel activity, particularly in tanker traffic. This pattern is consistent with a broader reconfiguration of global energy supply chains, in which U.S. export terminals assumed a more prominent role in meeting international demand for energy commodities.



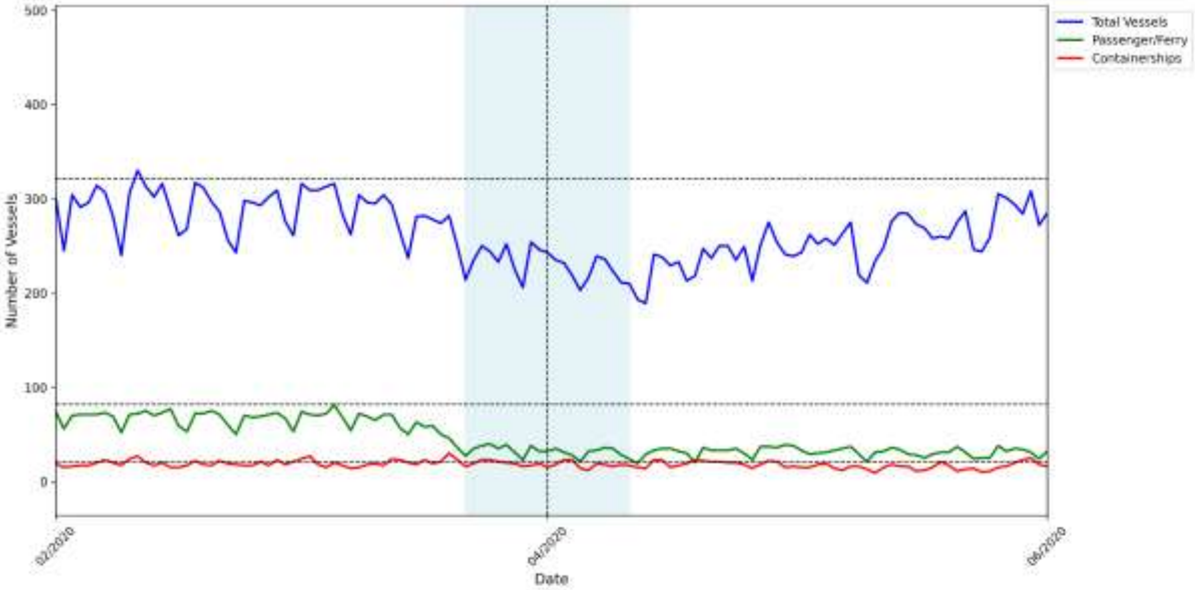
4.3 Covid -19 First Wave USA

The COVID-19 pandemic triggered one of the most significant disruptions in global economic activity in recent history, affecting international trade, transportation networks, and mobility on an unprecedented scale. According to the OECD, the pandemic caused sharp contractions in global demand, acute supply chain disturbances, and major shifts in freight and passenger movement patterns due to lockdown measures and travel restrictions, leading to far-reaching impacts on ports and maritime logistics (OECD, 2021).

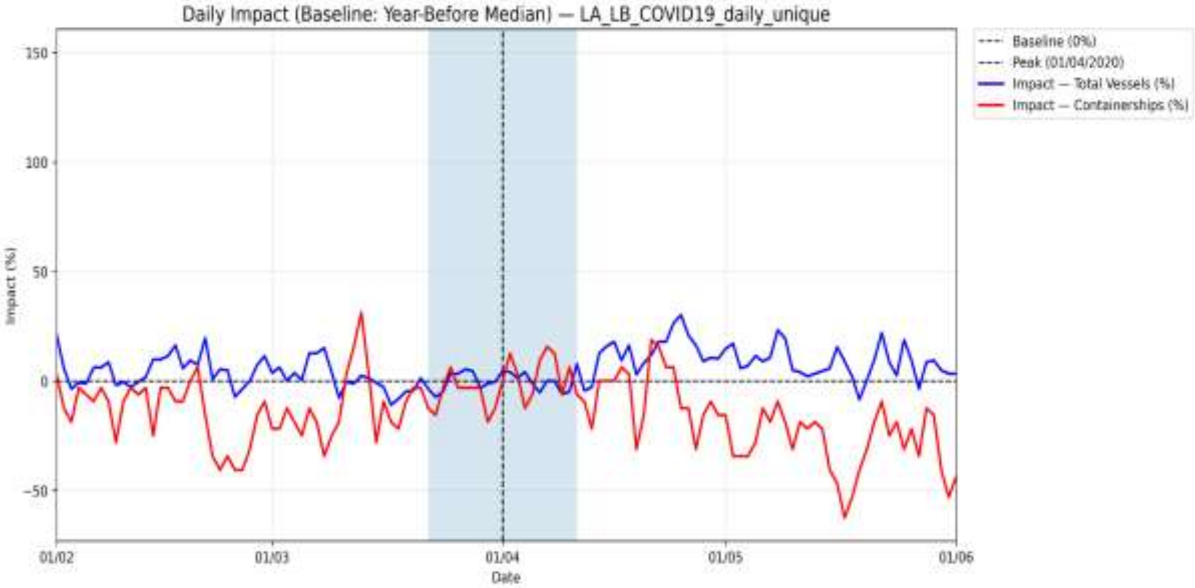


In the year before the onset of the pandemic, both the NY-NJ and LA-LB port complexes exhibited statistically stable baseline activity in vessel traffic across all categories. New York-New Jersey demonstrated a median daily distinct vessel count of 321 with relatively low variability, while Los Angeles/Long Beach recorded a median of approximately 246 vessels. These baseline conditions represent relatively stable operational regimes against which subsequent disruption patterns can be interpreted.

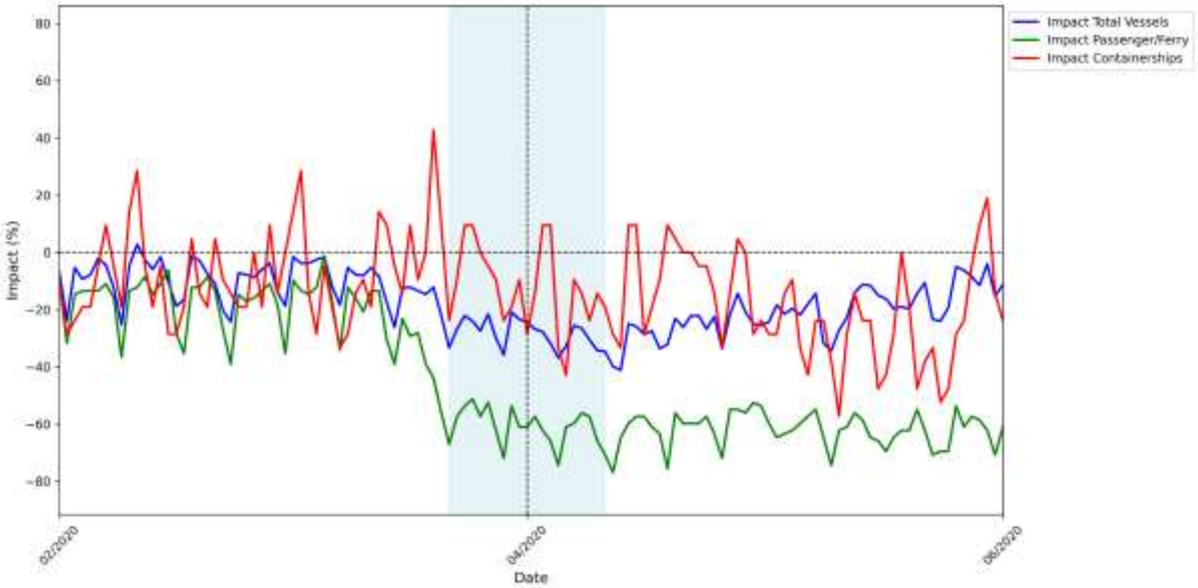
During the initial phase of the pandemic in 2020, the two regions diverged in their disruption dynamics. In NY-NJ, passenger and ferry activity contracted sharply as mobility restrictions took effect, reducing passenger traffic by roughly one-third relative to baseline levels. Total vessel presence also declined during the disruption period, reflecting the broader slowdown in economic activity and maritime mobility. Containership activity, however, remained comparatively resilient, suggesting that freight transport continued to operate despite the sharp contraction in passenger movements. This pattern indicates a demand-driven disruption primarily affecting mobility-related maritime activity rather than a complete breakdown of freight logistics.



By contrast, the LA-LB port complex followed a different trajectory. Although the early phase of the pandemic also introduced temporary disturbances, the subsequent period—particularly during 2021—shows a pronounced increase in containership activity and total vessel presence. Containership counts rise significantly above baseline levels, indicating a structural shift rather than short-term volatility.



This surge coincides with the strong rebound in U.S. consumer demand and the expansion of containerized imports, which contributed to the well-documented congestion phenomena observed in major West Coast ports.



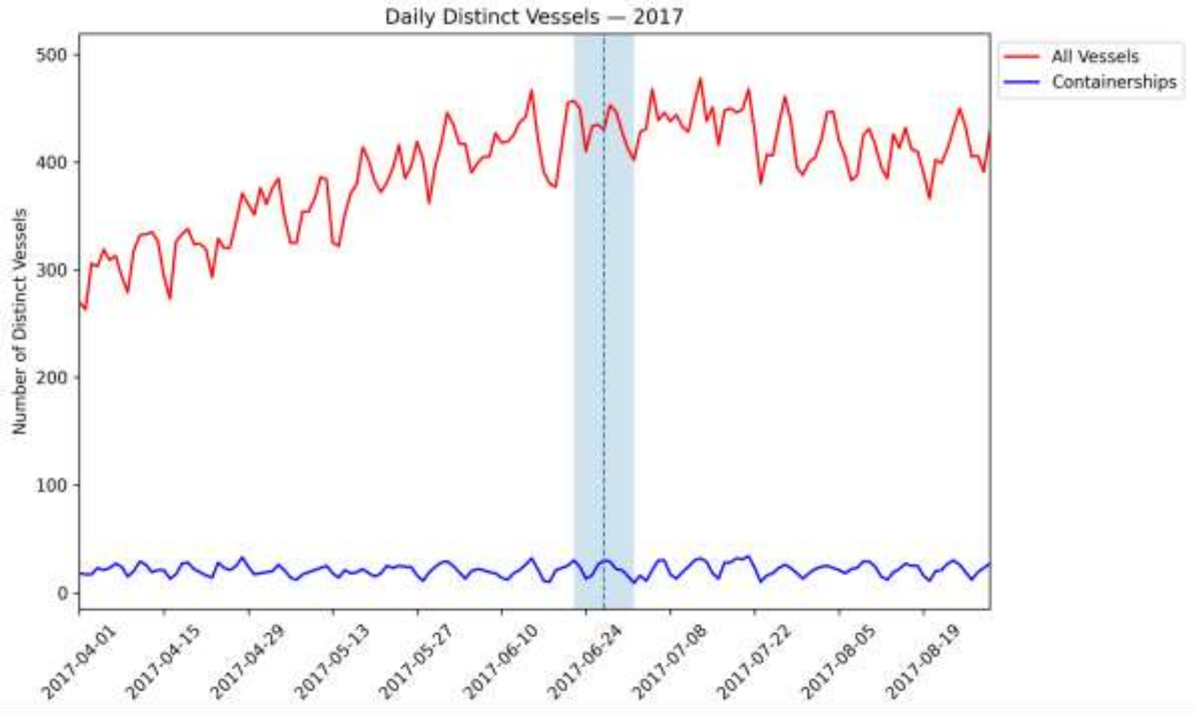
The year-after observations further highlight these differences. In the NY-NJ port system, vessel traffic gradually recovers but remains close to or slightly below baseline levels, particularly in passenger and ferry activity. In contrast, LA-LB experiences vessel counts that remain substantially elevated compared to pre-pandemic norms, reflecting persistent congestion and intensified container flows within the port system.

From a spatial perspective, these outcomes illustrate the heterogeneous nature of pandemic-related disruptions in maritime networks. While NY-NJ was primarily characterized by a contraction in mobility-related maritime demand, LA-LB experienced a demand-driven expansion in containerized trade that placed increasing pressure on port capacity and logistics infrastructure.

Overall, the COVID-19 disruption produced divergent operational responses across the two major U.S. port systems: a mobility-driven contraction in NY-NJ and a congestion-driven expansion in container traffic at LA-LB. These contrasting dynamics highlight how global economic shocks can manifest differently across port systems depending on their functional role within international shipping networks.

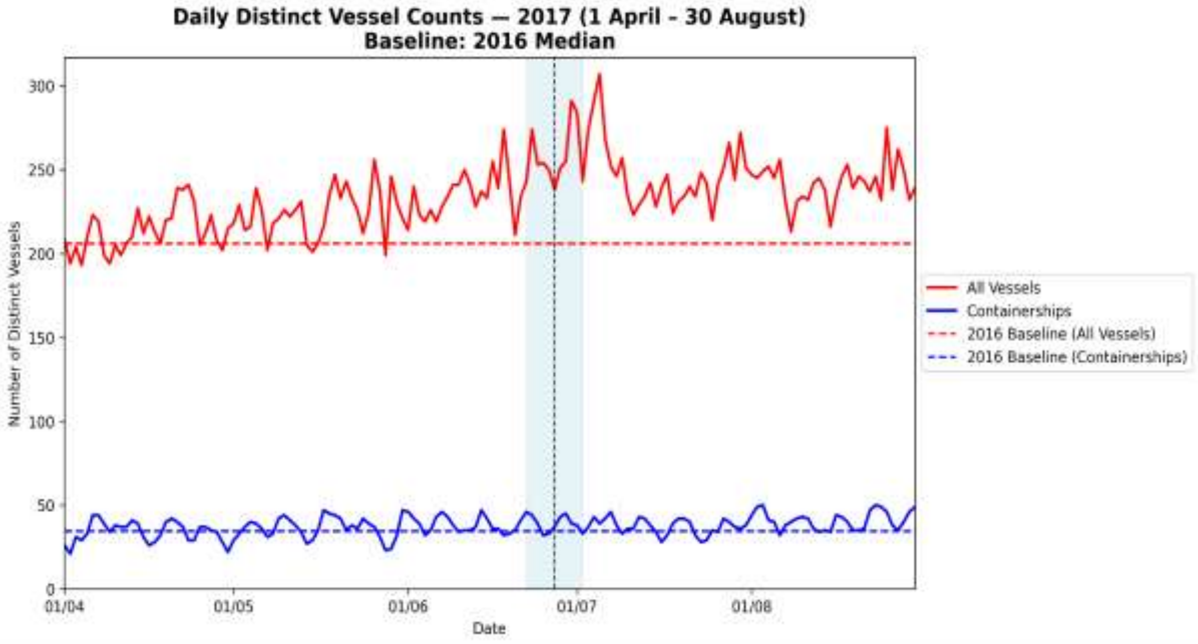
4.4 NotPetya Cyberattack USA Terminals

Port Complexity: Los Angeles-Long Beach & New York-New Jersey (Port Elizabeth), USA (Containerships). The June 2017 NotPetya cyberattack had a significant impact on global shipping operations, particularly affecting the information systems of A.P. Moller-Maersk, one of the world’s largest container shipping companies. According to Reuters (27 June 2017), Maersk reported that its global IT systems had been disrupted by the cyberattack, forcing some terminals to revert temporarily to manual operations while vessels were rerouted in order to maintain service continuity. The incident, widely attributed to a Russian-linked cyber campaign, constituted a disruption at the corporate and digital infrastructure level rather than a direct physical interruption of port infrastructure.

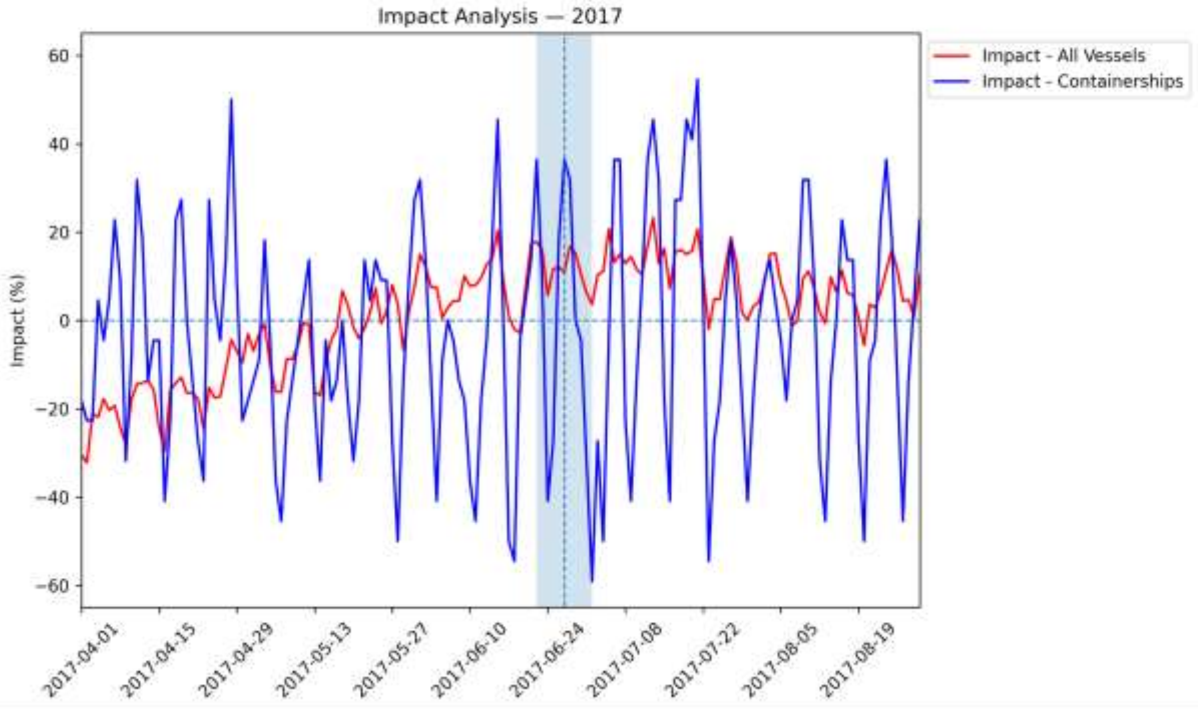


Across both gateway regions analysed the Los Angeles Long Beach port complex and the Port of New York and New Jersey (Port Elizabeth terminal area) the baseline series for the year preceding the incident display relatively stable traffic patterns. The daily distinct containership counts follow a gradual seasonal trajectory from early spring toward the summer months, with moderate dispersion around the central tendency. The corresponding statistical indicators, including median values, interquartile ranges, and coefficients of variation, suggest that vessel presence in these gateway regions exhibits normal intra-annual variability rather than structural instability during the baseline period.

During the event year (2017), the evolution of daily containership counts remains broadly consistent with this historical variability envelope. While short-term fluctuations appear around the time of the attack window, the series does not display an abrupt collapse in vessel presence or a sustained deviation from the baseline trajectory. Impact plots similarly indicate that deviations from the baseline oscillate around zero without forming a persistent negative shift. In statistical terms, the distribution of vessel counts during the event period retains comparable levels of dispersion and central tendency relative to baseline conditions. This absence of pronounced changes in distributional characteristics suggests that the event did not produce a structural break in containership activity within the analysed port regions.



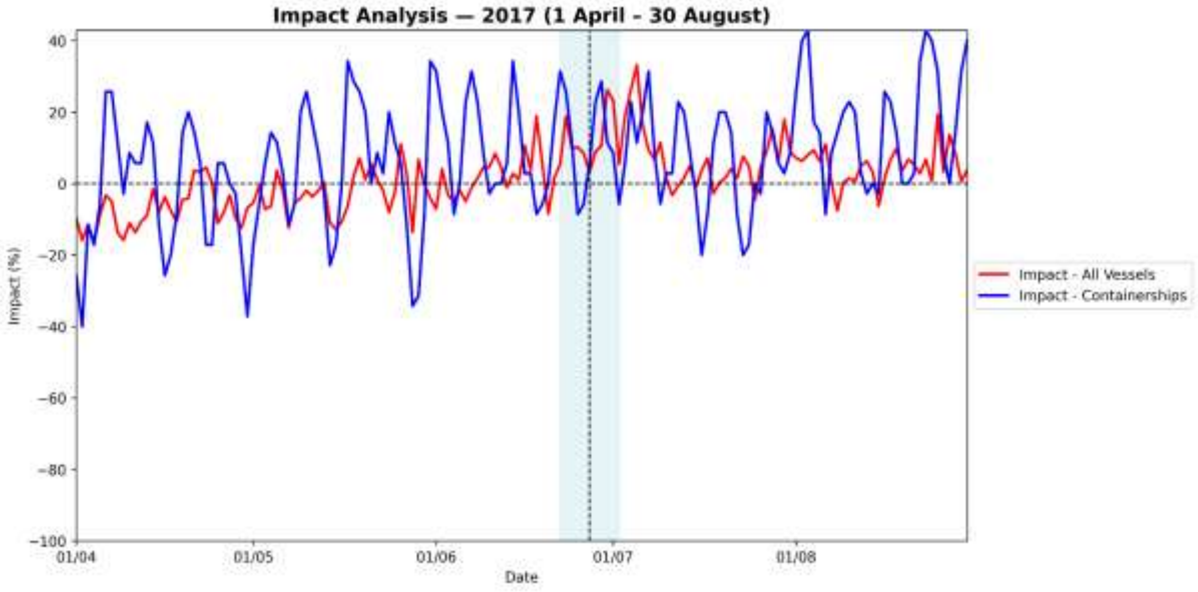
The post-event trajectory further supports this interpretation. Following the attack window, vessel presence continues along its expected seasonal progression without a pronounced rebound or backlog-clearance phase that would indicate congestion accumulation. Likewise, there is no extended interval of suppressed activity that could suggest prolonged operational disruption. Instead, the observed patterns indicate that vessel traffic remained within the range of normal operational variability throughout the analysed period.



A key element in interpreting this case lies in the nature of the disruption itself. The NotPetya attack targeted Maersk’s internal information systems and operational platforms rather than the physical infrastructure of the ports. As a result, the operational response involved rapid rerouting of vessels, manual cargo handling procedures in affected terminals, and coordination within liner alliance networks to maintain service continuity. Such adjustments may occur within the same port complex or between nearby terminals and therefore may not be observable through geographically aggregated vessel presence metrics. The methodology applied in this analysis captures vessel activity within defined spatial zones but does not distinguish operational changes occurring at the level of individual terminals or carrier-specific logistics networks.

From a spatial perspective, both Los Angeles-Long Beach and the NY NJ gateway operate as highly diversified container port complexes hosting multiple terminal operators and liner services. This structural redundancy and carrier diversity likely reduced the localized exposure of these gateways to a disruption affecting a single shipping line’s digital infrastructure. The absence of a clear decline in overall vessel presence suggests that port-level activity remained resilient despite the corporate-level operational shock.

Consequently, the NotPetya incident cannot be classified as a structural disruption in the spatial traffic patterns of these U.S. container gateways. The data do not indicate congestion accumulation, persistent negative departures from baseline vessel activity, or statistically observable regime shifts in the time series. Instead, the observed dynamics are consistent with temporary operational volatility that was largely absorbed by the broader port and shipping network.



Overall, the NotPetya case illustrates how a major cyber disruption affecting a leading global carrier may produce substantial operational challenges at the corporate level while leaving only limited traces in aggregated spatial vessel-traffic indicators at major port gateways.

4.5 Maritime Accidents USA

4.5.1 Collision on Baltimore Bridge and Collapse Case

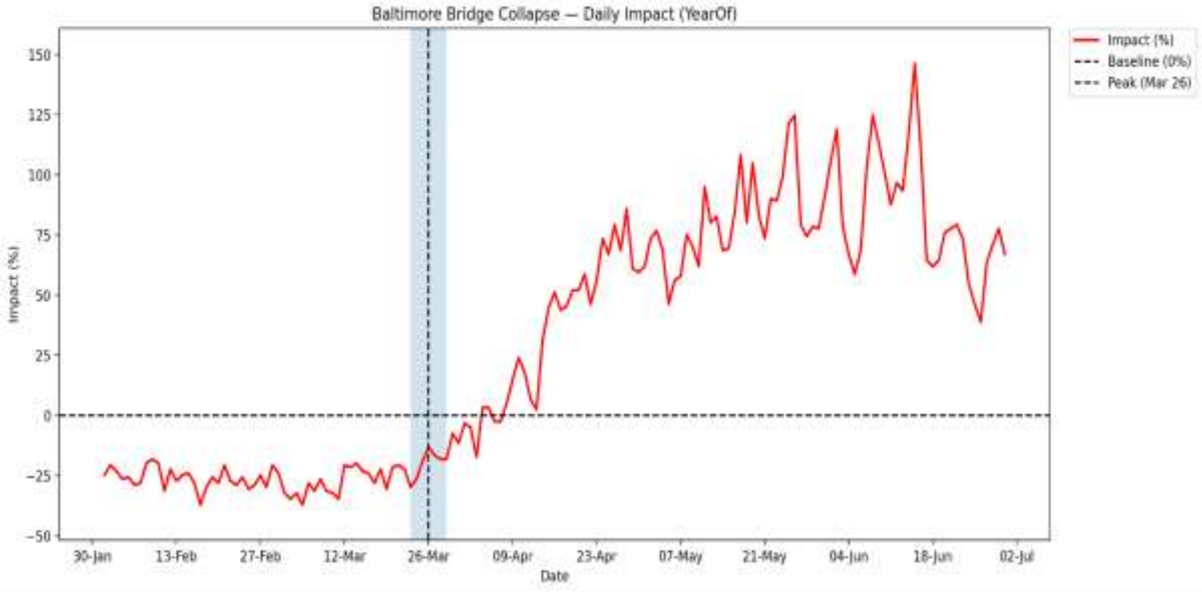
The collapse of the Francis Scott Key Bridge in Baltimore on 26 March 2024 constituted a sudden and severe infrastructure failure that immediately disrupted maritime access to the Port of Baltimore. Following the incident, vessel movements were suspended and multiple ships were forced to anchor outside the port area, while inbound and outbound traffic was halted (Reuters, 2024). This operational interruption provides the contextual foundation for interpreting the AIS-based vessel traffic patterns observed in the broader maritime zone.

Prior to the incident, daily vessel traffic in the area remained relatively stable and generally below the historical baseline derived from the year-before period. In contrast, the vessel count distribution in the event year indicates a noticeable shift in activity levels after the accident. Overall traffic levels became consistently higher than the historical baseline, suggesting a change in the operational regime of the area rather than normal variability.

Dispersion indicators further support the presence of this change. Variability in vessel presence increases during the event year, indicating more irregular traffic patterns and a wider spread of daily vessel counts compared with the year-before period. The upper portion of the distribution becomes noticeably higher, suggesting that days with elevated vessel presence occur more frequently after the disruption.

The distributional characteristics reinforce this interpretation. In the event year, vessel activity appears more evenly spread across a broader range of values, while the year-before distribution shows more occasional peaks rather than sustained accumulation. This pattern suggests that higher vessel presence becomes more persistent during the disruption period rather than being driven by isolated spikes.

This pattern is also visible in the graphical comparison of vessel traffic. In the vessel count curve of the event year, activity remains relatively stable before the incident but begins to increase steadily afterwards.

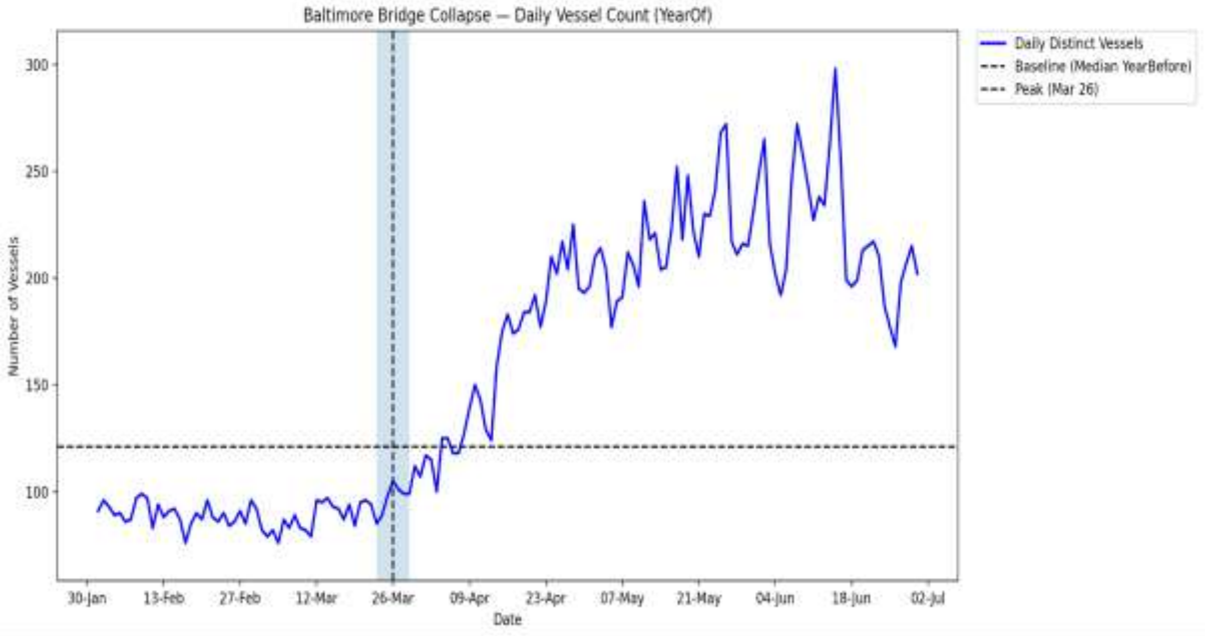


The curve gradually moves above the baseline and remains elevated for an extended period. By contrast, the diagram of the year before the incident shows a more gradual evolution of traffic without a comparable shift following the same calendar date.

A similar pattern appears in the impact curve for all ships. Before the incident, the impact curve fluctuates around or below the baseline, indicating traffic levels close to normal conditions. After the incident, the curve becomes consistently positive and remains elevated for a prolonged period, indicating that vessel presence in the broader maritime area increased relative to typical levels.

Importantly, the disruption does not manifest as a collapse in vessel presence within the Big Square spatial window. Instead, the observed pattern suggests congestion accumulation. While direct port access was restricted due to channel obstruction and safety measures (Reuters, 2024), vessels continued to approach and remain within the wider maritime area, producing queuing effects and a higher concentration of ships around the port approaches.

The recovery pattern appears gradual rather than immediate. Elevated vessel presence persists for an extended period after the incident, indicating ongoing operational adjustments rather than a rapid return to normal conditions. It should also be noted that a year-after comparison could not be conducted in this analysis because official AIS datasets for the following year were not yet available at the time of the study.

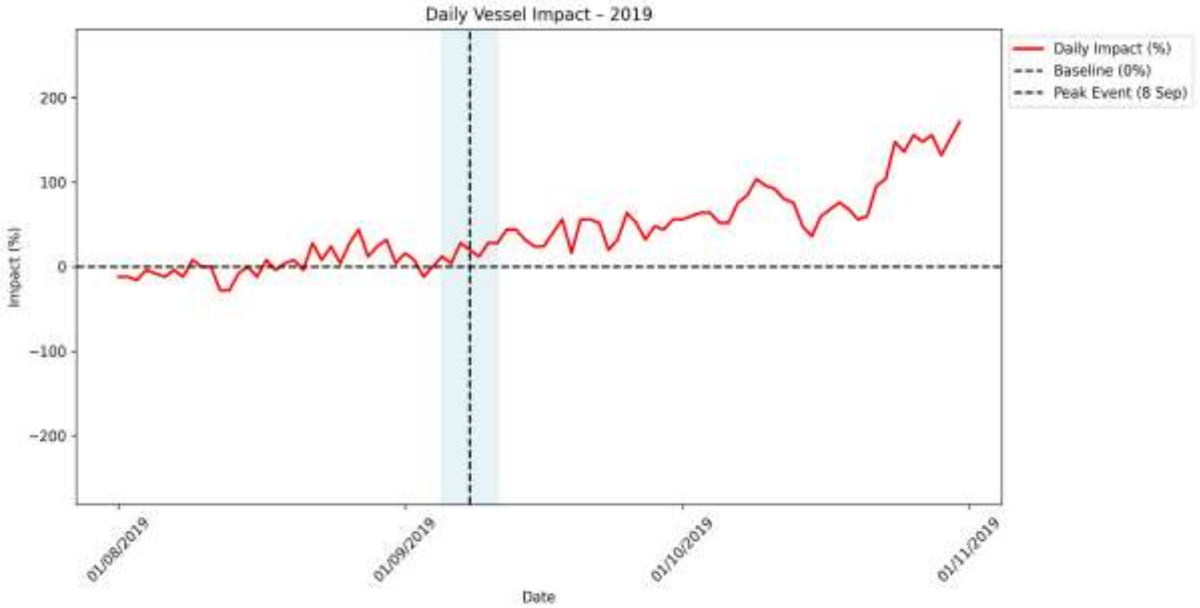


Overall, the Baltimore bridge collapse can therefore be interpreted as a structural operational disruption characterized primarily by congestion accumulation rather than a decline in maritime activity. The evidence suggests that the accident reduced effective navigational capacity while vessel arrival demand remained active. As a result, ships accumulated within the broader maritime buffer zone, generating prolonged congestion in the port approach system.

4.5.2 Capsizing of Golden Ray Case

The capsizing of the cargo vessel MV Golden Ray on 8 September 2019 in the St. Simons Sound adjacent to the Port of Brunswick resulted in temporary navigational restrictions in the port's access channel and initiated a coordinated response from the U.S. Coast Guard and salvage teams. According to contemporaneous reporting drawing on Reuters and Associated Press sources, the vessel's overturning prompted operational constraints while rescue and recovery operations were carried out, with all 24 crew members ultimately accounted for without loss of life (Business Insider, 2019).

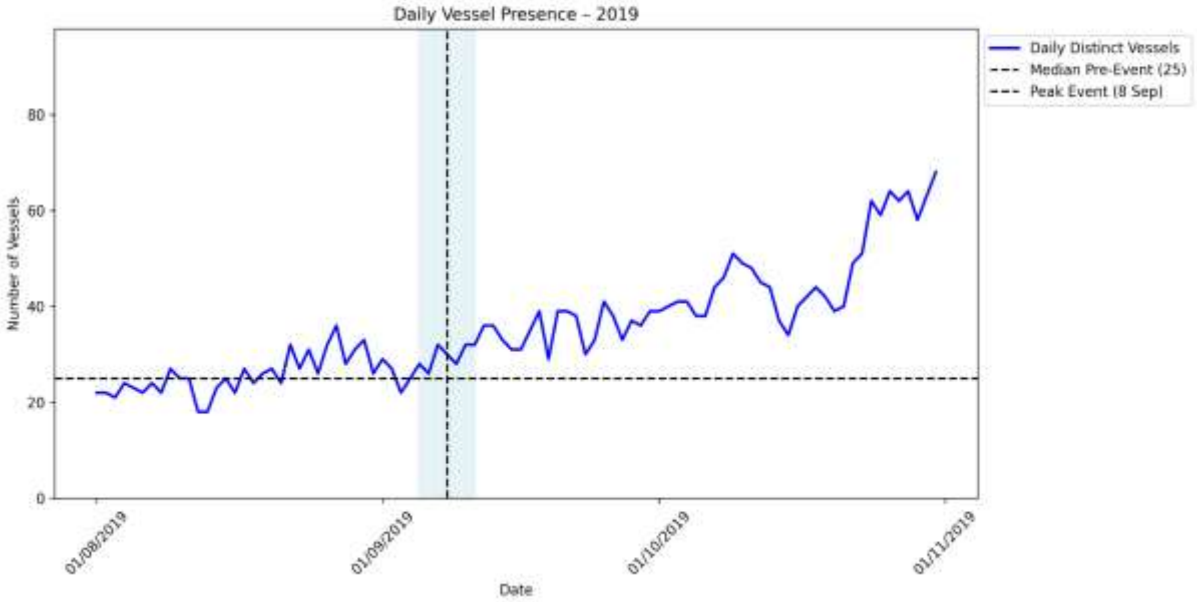
Prior to this incident, vessel presence at Brunswick exhibited a relatively stable pattern. Baseline statistics for the year preceding the disruption indicate moderate variability around a consistent median level of daily vessel activity. The corresponding vessel presence curve in the year before the incident fluctuates within a relatively narrow range, suggesting stable operational conditions and predictable traffic flows in the port area.



Immediately following the capsizing, the vessel presence curve in the event year does not display the abrupt collapse or sudden accumulation that would normally be expected if the closure had produced a strong queuing effect at the entrance of the bay. Instead, vessel counts remain broadly comparable to the preceding pattern during the days surrounding the incident and gradually increase later in the observation period. This temporal evolution indicates that the operational adjustments to port access and scheduling were absorbed without generating a sharp backlog of vessels waiting to enter the port.

This interpretation is further supported by the impact curve in the event year, which does not reveal a clear negative shock around the date of the accident. Rather than a pronounced discontinuity, the curve exhibits moderate fluctuations around the baseline followed by a gradual upward tendency later in the period. Such behaviour suggests that vessel movements adapted progressively to the temporary navigational restrictions without producing a structural interruption in maritime traffic.

The comparison with the vessel presence curve in the year after the incident further clarifies the broader traffic dynamics. In that period, vessel activity appears noticeably higher and more variable, indicating that the increase observed after the accident is more consistent with a general expansion of port activity rather than a direct consequence of the capsizing event itself. The overall pattern therefore does not indicate traffic diversion, sustained congestion at the entrance, or a long-term decline in port usage.



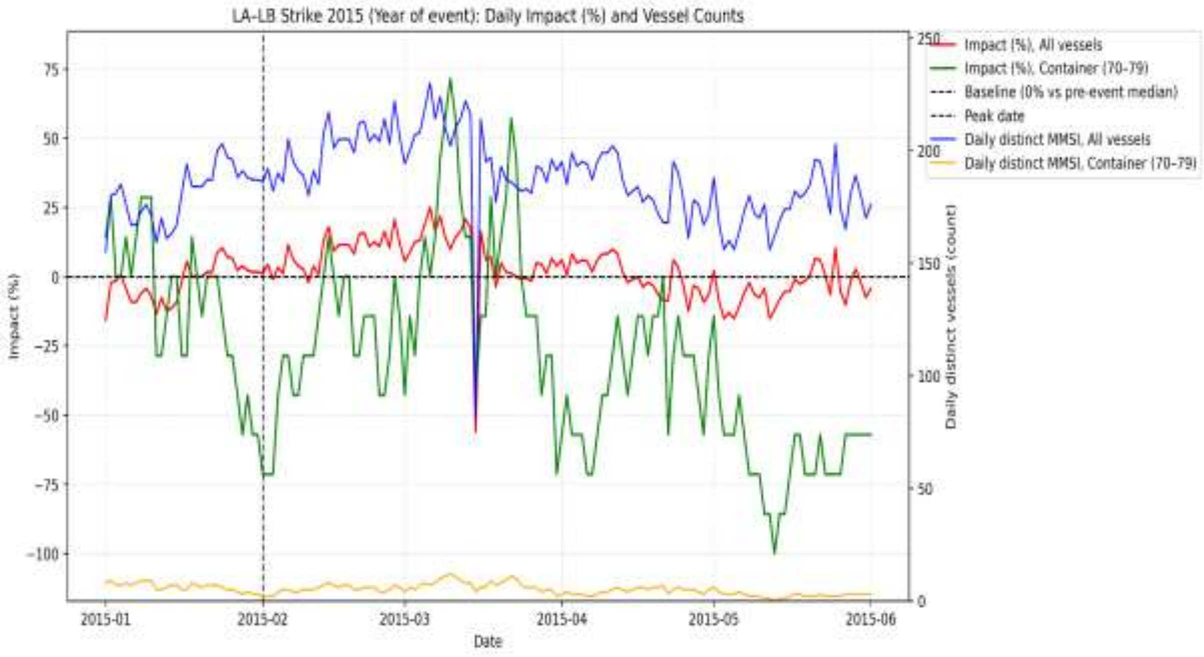
In disruption taxonomy terms, this case is most consistent with a temporary operational disturbance rather than a structural disruption of maritime traffic. The observed patterns suggest limited short-term adjustments in vessel movements while the port remained broadly functional.

From a disruption logic perspective, the Golden Ray capsizing illustrates how a significant maritime accident in a port approach area may introduce localized operational friction without fundamentally altering the structure of vessel flows. The traffic patterns visible in the vessel presence and impact curves indicate that the disturbance was gradually absorbed, allowing the port system to return to its normal trajectory without prolonged disruption.

4.6 ILWU PMA Labour Dispute 2014-15

The 2014/2015 labor dispute affecting the Los Angeles-Long Beach port complex represents a significant operational disruption rather than a short-term fluctuation in port activity. It should be noted that AIS data from the Marine Cadastre dataset began in January 2015, while labor tensions had already been developing during 2014. As a result, there is no fully reliable pre-disruption baseline for vessel activity before the escalation of the dispute. Consequently, the early 2015 period should be interpreted cautiously, as the reference median for January may already reflect partially disrupted operational conditions.

During the event year, daily vessel activity exhibits clear instability. In the diagram of the event year, the all ships impact curve shows repeated negative deviations around the period of peak labor tensions. The corresponding vessel count curve also displays pronounced fluctuations, indicating a temporary loss of operational regularity in vessel movements. These patterns suggest episodic operational disturbances rather than normal seasonal variation.



The impact appears more pronounced for containership traffic. In the same diagram, the **containership impact curve** shows stronger negative deviations and greater variability compared with the overall vessel activity. This pattern is consistent with the nature of the disruption, as container handling operations are particularly sensitive to labor productivity at terminals.

The recovery pattern also provides useful insight. Instead of an immediate return to stable activity levels, vessel presence remains uneven for a period after the peak disruption, reflecting operational adjustments, backlog clearance, and schedule reorganization. When compared with the diagram of the following year, vessel activity appears considerably more stable, suggesting that the instability observed during the event year is closely associated with the labor dispute.

From a spatial perspective, the Los Angeles Long Beach port complex functions as the primary U.S. gateway for transpacific container flows. In such a highly connected maritime node, disruptions do not necessarily appear as visible anchorage congestion. Shipping lines often respond through operational adjustments such as blank sailings, schedule changes, or port omissions. Therefore, the temporary decline in active vessel presence observed in the event-year diagram is more likely to reflect reduced operational efficiency and service adjustments rather than simple vessel queuing.

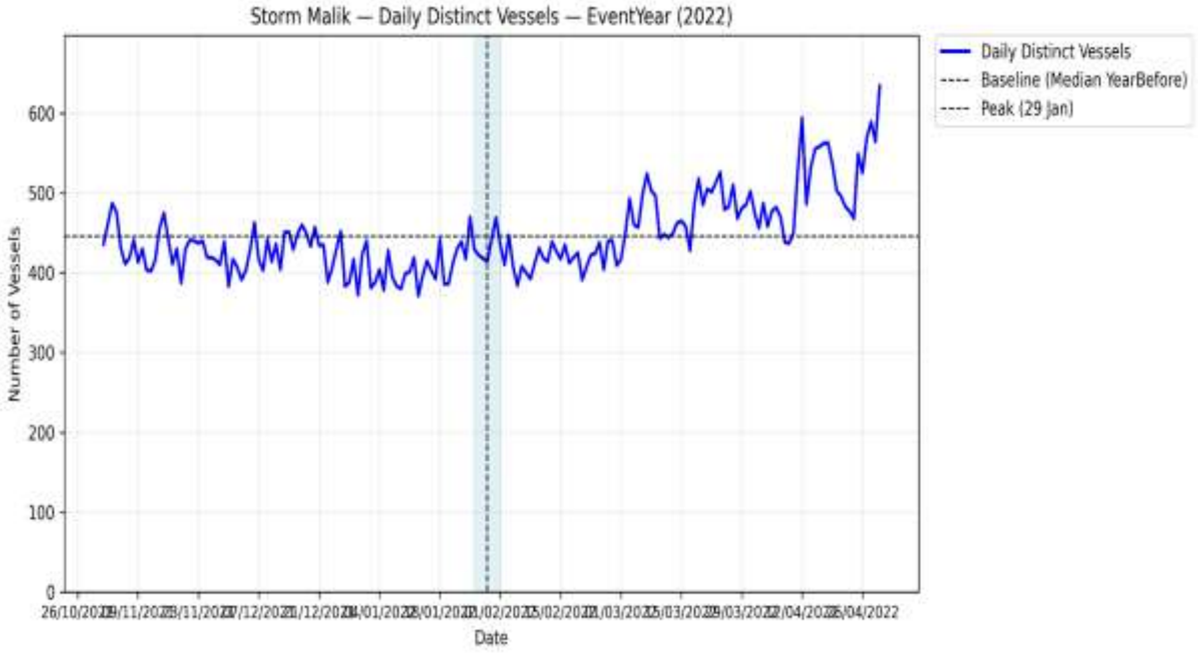
Overall, the observed patterns indicate a substantial disruption in port operations linked to institutional and labor-related factors. The temporary decline in vessel presence, the increased variability in daily activity, and the stronger impact on container traffic all point to a period of reduced operational stability within the port complex. While the disruption does not represent a complete breakdown of port activity, it illustrates how labor disputes can generate significant operational disturbances in a major maritime gateway.

The LA-Long Beach strike therefore highlights how labor-related institutional frictions can affect the functioning of key maritime hubs. The gradual return to more stable vessel activity in the following year suggests that the disruption was closely tied to the period of labor tensions and that recovery required time for operational adjustments and backlog clearance within the port system.

4.7 Natural Disruption Denmark

Storm Malik was a severe winter storm that affected the Nordic region in late January 2022, bringing strong winds and widespread weather impacts across Denmark and neighbouring countries. (Associated Press, 2022).

Against this context, the pre-event traffic pattern in Danish territorial waters appears broadly stable in baseline terms. The distribution observed during the year preceding the event is centred around the baseline median (446), with relatively limited dispersion and no indication of major structural changes in vessel activity. This stability suggests that maritime traffic in the area follows a relatively predictable operational pattern, where daily vessel presence fluctuates within a stable range rather than exhibiting strong trends or abrupt changes.



During the event year, vessel traffic remains close to the baseline level throughout the period surrounding the storm. The median value is slightly lower than the baseline (437 compared to 446), indicating only a minor reduction in activity during the event window. However, the overall traffic pattern does not show a clear collapse or abrupt disruption in vessel movements. Instead, the observed fluctuations remain within the normal operational variability of the system.

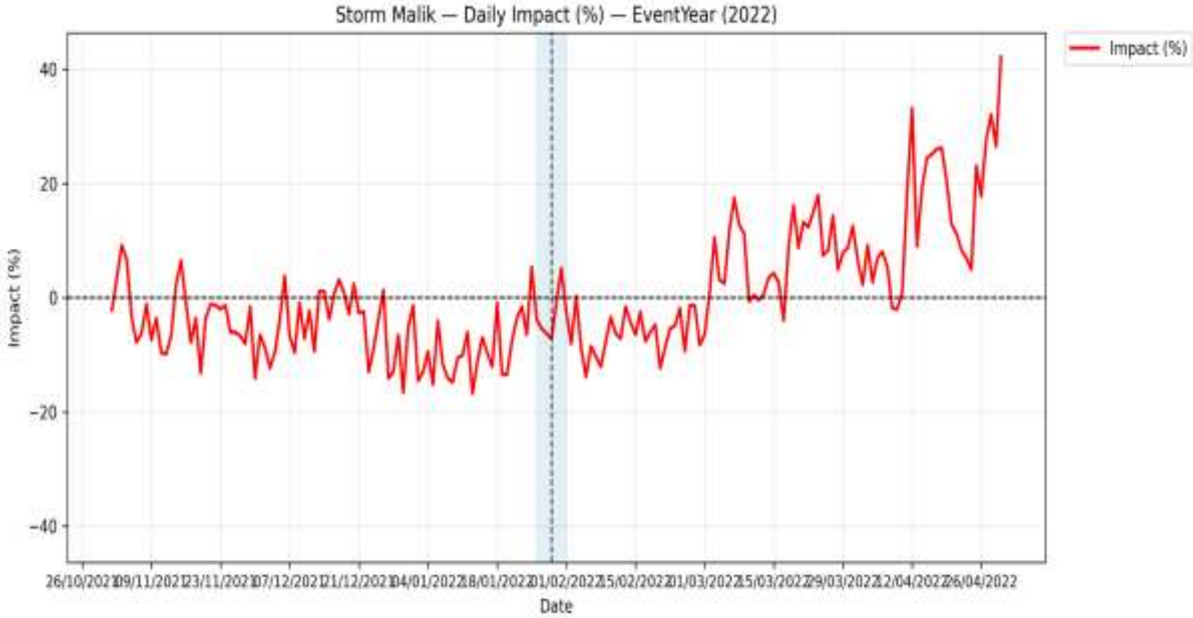
The dispersion of the distribution during the event year appears slightly higher compared to the baseline period, indicating somewhat greater short-term variability in daily vessel counts. This pattern is consistent with minor operational adjustments that may occur during severe weather conditions, such as temporary delays, speed reductions, or small changes in vessel scheduling. Nevertheless, these variations do not suggest a substantial disruption in overall maritime traffic levels.

The recovery pattern further supports this interpretation. The distribution observed in the following year returns to a central level very close to the baseline (median 444 compared to the baseline median of 446). This indicates that the event did not produce any lasting change in vessel traffic levels within the study area. While some variability remains present in daily vessel counts, the overall pattern is consistent with normal operational dynamics.

A comparison with the corresponding periods of the previous and following years further confirms this interpretation. Similar seasonal increases in vessel activity are visible after the winter period across all three years, suggesting that the gradual rise in vessel traffic observed after February reflects normal seasonal maritime activity rather than a recovery from disruption. The diagrams corresponding to the year-before and year-after periods are provided in the Appendix for reference.

From a spatial perspective, Danish territorial waters function as a major maritime transit corridor between the North Sea and the Baltic Sea. The region supports dense commercial shipping flows as well as significant short-sea and ferry traffic. In such transit environments, weather events may temporarily influence vessel operations by affecting timing or navigation conditions, but they rarely lead to sustained reductions in overall traffic volumes.

Taken together, the statistical indicators and graphical evidence suggest that Storm Malik did not generate a significant disruption in maritime traffic within Danish territorial waters. Vessel activity remained close to baseline levels throughout the event period, and the overall traffic dynamics remained consistent with the normal seasonal pattern of maritime operations.

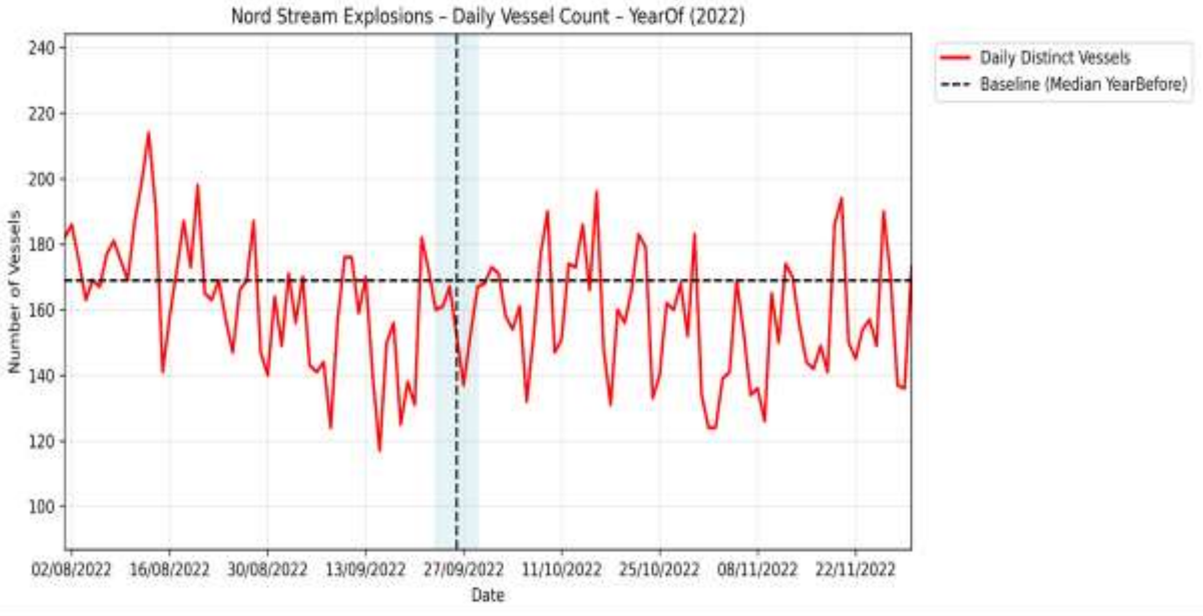


The observed pattern is best classified as temporary operational volatility with minimal systemic impact, rather than a structural disruption or a major traffic shock. Severe winter storms primarily affect operational conditions such as vessel speed, timing of arrivals, and short-term scheduling decisions. These operational adjustments may introduce minor variability in daily vessel counts, but they do not necessarily alter the overall demand for maritime transport in major transit corridors. Consequently, the impact of Storm Malik appears limited to small short-term fluctuations rather than a significant disruption of the maritime traffic system.

4.8 Geopolitical Shock Denmark

On 26 September 2022, a series of underwater explosions damaged the Nord Stream 1 and Nord Stream 2 gas pipelines in the Baltic Sea near the Danish and Swedish maritime zones, causing major gas leaks and triggering heightened security and monitoring activity in the surrounding maritime area (Reuters, 2022).

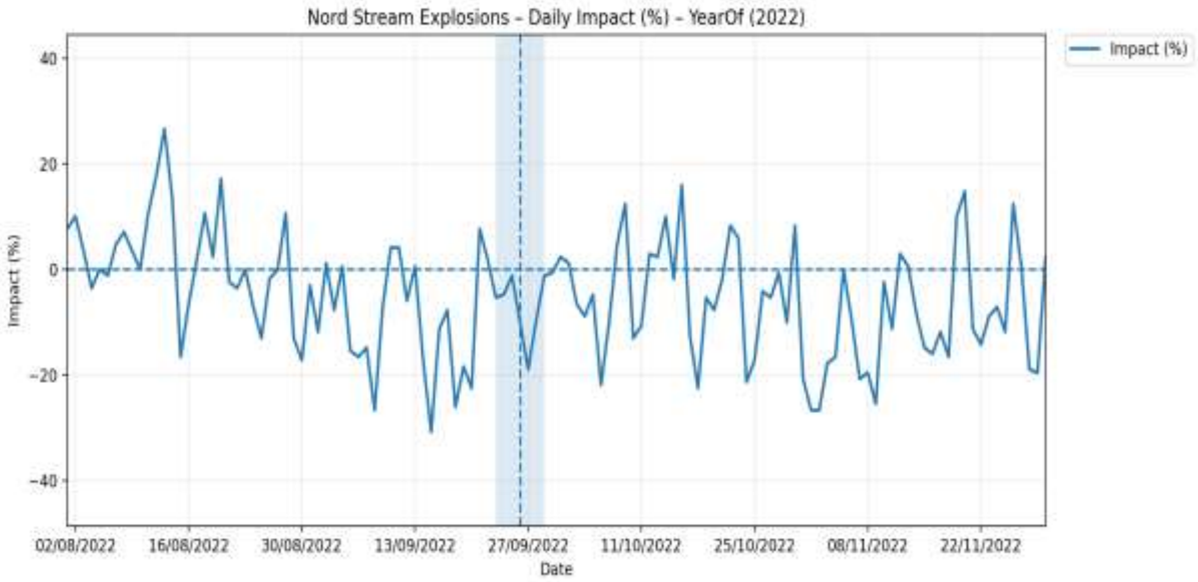
The vessel traffic patterns observed in the Danish territorial waters surrounding the Nord Stream pipeline area suggest that the pre-event period was characterized by relatively stable maritime activity. As shown in the curve of the year-before diagram, daily vessel presence fluctuates within a relatively consistent operational range, reflecting a steady level of regional traffic associated with routine Baltic Sea transit routes and nearby maritime operations. This stability provides a reliable baseline for assessing whether the pipeline explosions produced measurable disruptions in the observed traffic patterns.



In the year of the event, the immediate reaction in vessel activity appears moderate rather than abrupt. The curve in the event-year diagram does not display a sharp collapse exactly at the moment of the explosions, suggesting that the incident did not trigger an instantaneous shutdown of maritime activity within the broader study area. Instead, the traffic pattern indicates a gradual reduction in vessel presence during the following weeks. This change is also reflected in the impact curve of the event year, where deviations from the baseline become more frequently negative after the incident. The pattern therefore suggests a moderate downward shift in vessel presence rather than a short-lived operational shock.

The evolution of traffic during the subsequent period reinforces this interpretation. Following the initial adjustment phase after the explosions, the curve in the event-year diagram continues to fluctuate but generally remains below the baseline level for a considerable portion of the observation window. Although daily variability persists, which is typical in maritime traffic systems, the overall pattern suggests that vessel activity stabilizes at a somewhat lower level compared with the year before the event. The absence of a rapid return to the baseline indicates that the observed change reflects more than temporary volatility.

The comparison with the year after the event provides additional context for interpreting the disruption. As illustrated by the curve in the year-after diagram, vessel activity appears to partially recover compared with the event year, indicating that the maritime system gradually re-stabilizes after the initial shock. Nevertheless, the overall level of activity remains slightly lower than that observed in the year-before diagram. This pattern of partial recovery combined with continued deviation suggests that the effects of the incident extended beyond the immediate operational response period.



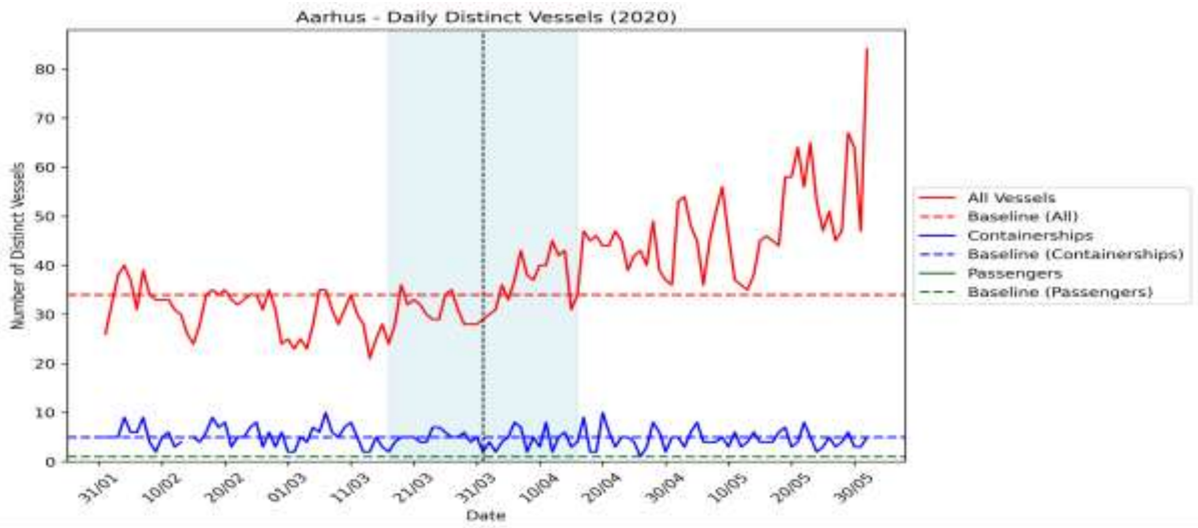
From a spatial perspective, the interpretation of this pattern is closely linked to the geographic characteristics of the study area. The Nord Stream explosions occurred in a localized section of the Baltic Sea that lies within an important maritime corridor connecting several Northern European ports. However, vessels transiting the Baltic Sea have multiple navigational options within the wider sea space. As a result, safety zones, monitoring operations, or perceived navigational risks in the vicinity of the pipeline damage may have encouraged vessels to slightly adjust their routes. Such adjustments would reduce the number of AIS signals recorded inside the specific analysis box without necessarily implying a broader decline in Baltic maritime activity.

Taken together, the evidence suggests that the Nord Stream explosions did not generate an abrupt operational shutdown of maritime traffic in the surrounding Danish waters. Instead, the observed patterns point to a moderate but persistent reduction in vessel presence within the defined study area, accompanied by gradual stabilization over time. The pattern is therefore most consistent with a rerouting effect, where vessels continue operating within the regional maritime network but slightly alter their local navigation paths in response to the incident and the associated security environment.

In this context, the disruption mechanism can be interpreted as a localized spatial adjustment within the maritime traffic network. The explosions created a sensitive operational environment around the damaged pipeline corridor, likely prompting precautionary routing behaviour and increased maritime surveillance. Consequently, part of the vessel traffic that previously passed directly through the analysed area may have shifted slightly outside the observation zone. This spatial redistribution of traffic explains why the AIS-based vessel counts decline without displaying the characteristics of a complete traffic interruption, supporting the classification of the event as a rerouting-driven disruption rather than a structural breakdown of regional maritime activity.

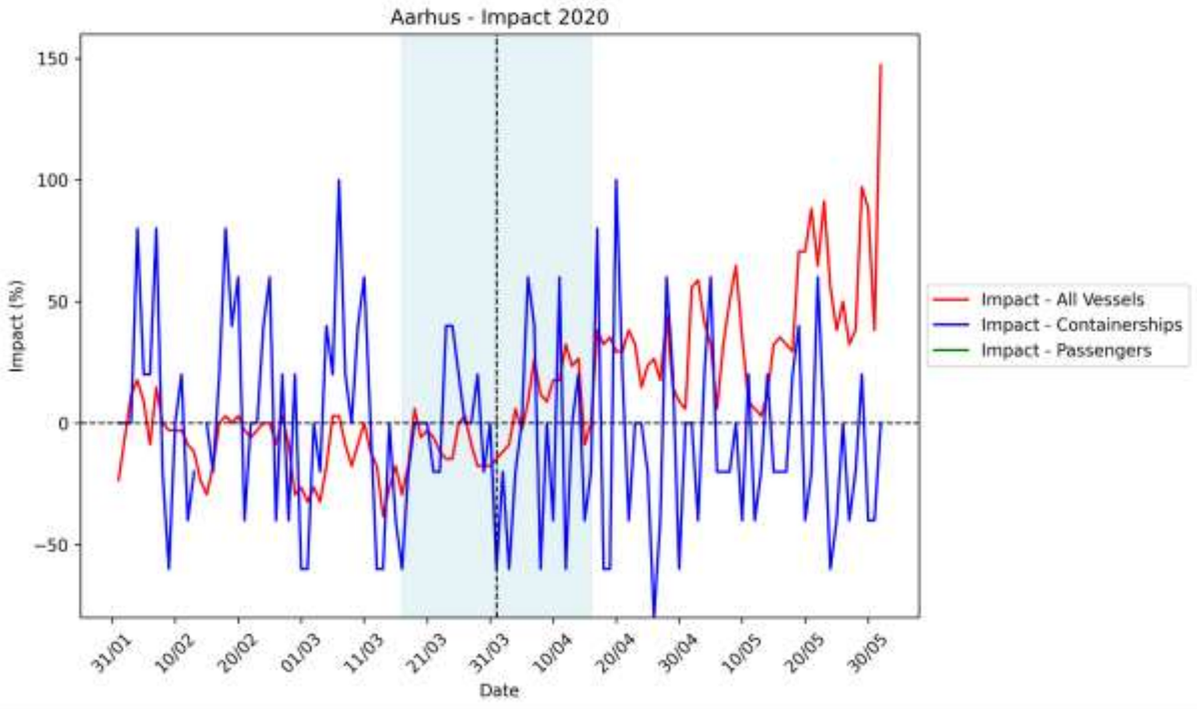
4.9 Covid -19 First Wave Denmark

The first COVID-19 wave in Denmark was accompanied by rapid nationwide restrictions from mid-March 2020 (school and public-sector closures, border controls and limits on social activity), creating an abrupt mobility and demand shock for transport services. Within the Danish “basic ports” system examined here (Aarhus, Copenhagen and Rødbyhavn), the AIS-derived daily vessel series suggests that the shock did not translate into a uniform collapse of overall port-area vessel presence. Instead, the patterns indicate a differentiated response between vessel categories: passenger-related activity weakens during the disruption window, while cargo-related movements, particularly around the larger ports, remain comparatively stable and later display signs of increased activity.



In the pre-event segment, vessel activity across all three locations fluctuates around relatively stable levels. In the diagrams of the year before the event, the curves for all vessels at Aarhus, Copenhagen and Rødbhavn remain close to their respective baseline levels with moderate dispersion. The containership curves display stronger relative variability, which is expected because the number of such calls is comparatively small. The passenger curves are also relatively volatile for the same reason. Importantly, the diagrams of the year before the disruption window do not show any systematic downward trend that could explain a structural decline at the moment of the event.

Across the three ports, the shaded disruption window does not coincide with a synchronized collapse of total vessel presence. In the diagrams of the event year, the curves for all vessels in Aarhus and Copenhagen continue to fluctuate close to their baseline levels during the disruption period, suggesting that essential cargo movements and operational port activity continued. However, the impact diagrams reveal a clearer compositional effect: passenger activity tends to remain below its baseline for extended intervals, while cargo-related movements display greater short-term variability rather than a sustained decline.

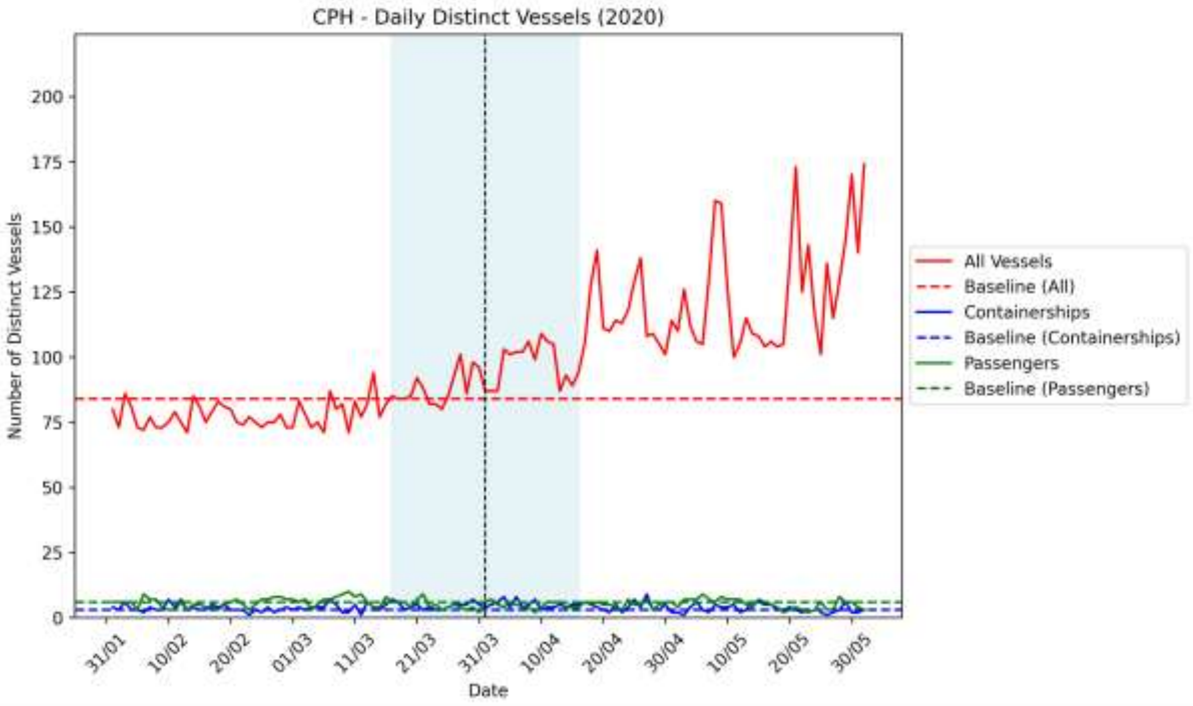


In the diagrams of the event year for Copenhagen in particular, the passenger curve frequently lies below the baseline during and after the disruption window, consistent with travel restrictions and reduced mobility demand. In contrast, the containership curve shows irregular oscillations around the baseline, reflecting schedule adjustments, uneven arrivals or operational "lumpiness," rather than a structural interruption of cargo services.

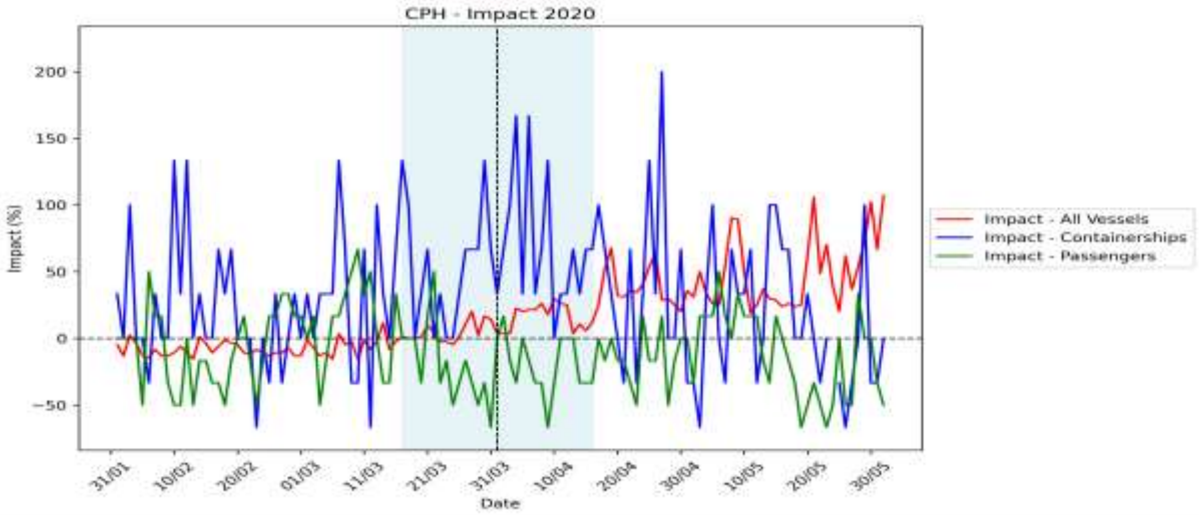
The most visible pattern after the disruption window is not a rebound from a sharp collapse, but a gradual upward deviation in total activity, particularly in Aarhus and Copenhagen. In the diagrams of the event year, the curve for all vessels begins to rise after the disruption window and continues increasing toward the end of the observation period. This tendency is especially clear in the diagrams comparing the three years, where vessel presence in the later months exceeds the levels observed earlier in the period.

This pattern suggests that the system transitions from a short-term disturbance to a phase of operational adjustment and accumulation. When schedules are disrupted and rotations are reorganized, vessel arrivals can become uneven, temporarily increasing the number of distinct vessels present in port areas. At the same time, the passenger curves do not show a similarly strong recovery, remaining generally weaker than in the reference year.

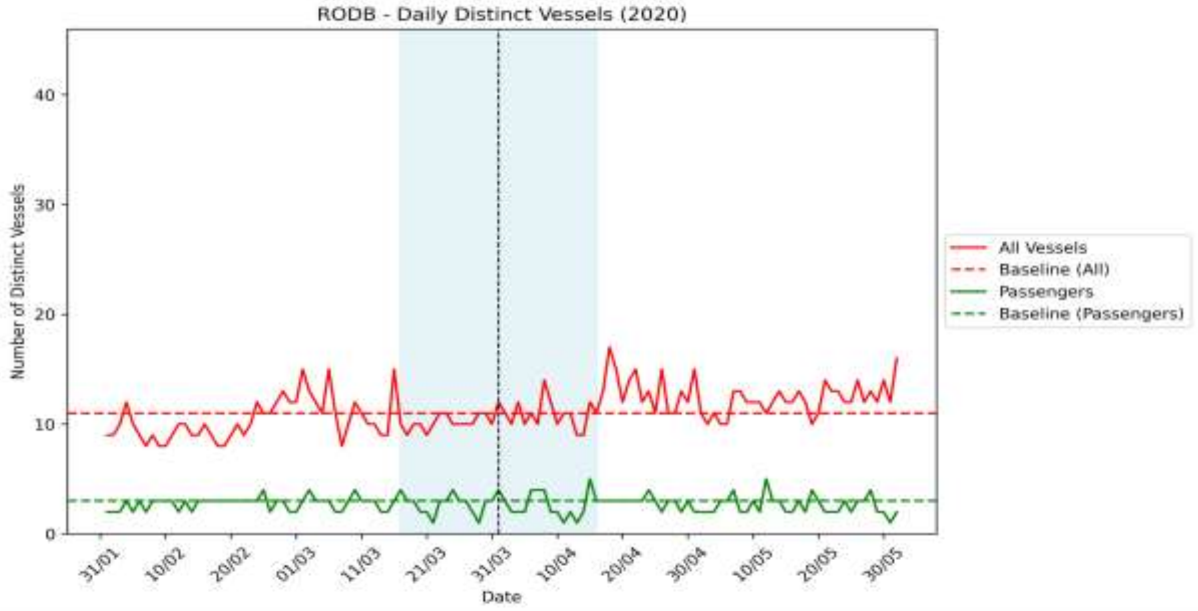
The diagrams of the year before the disruption provide an important reference point. Both Aarhus and Copenhagen already show moderate strengthening in total vessel presence during the spring months, meaning that part of the increase observed later in the event year may reflect normal seasonal dynamics. Nevertheless, the diagrams of the event year display greater variability and more pronounced fluctuations in total vessel presence, especially in Copenhagen.



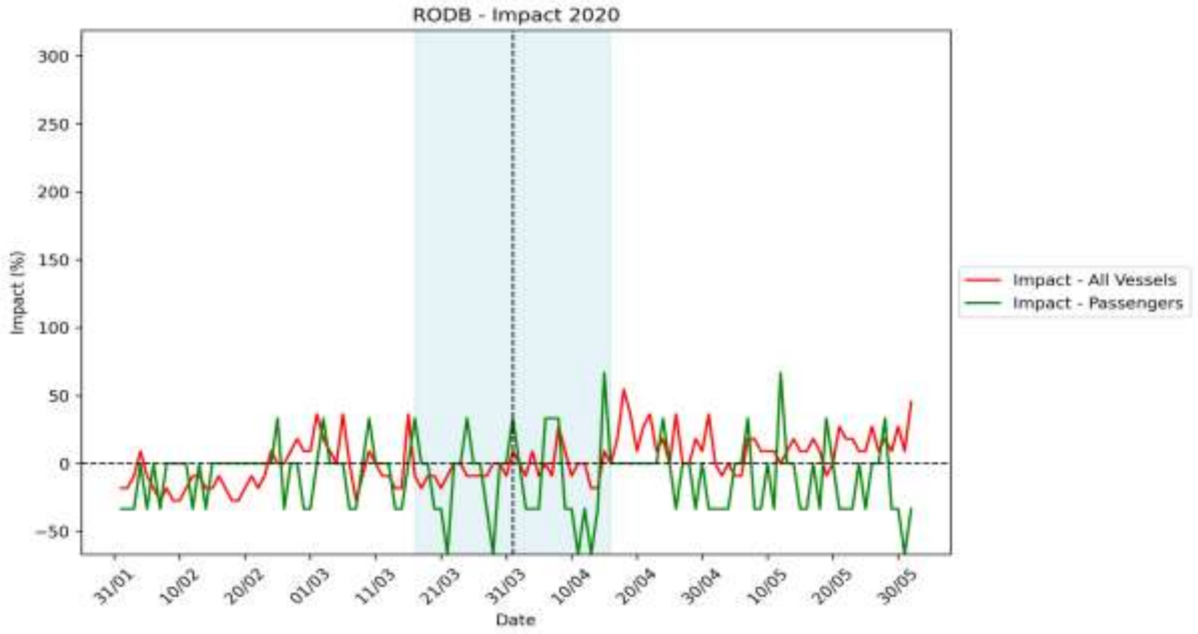
The passenger series also differs clearly from the reference year: in the diagrams of the year before the event, passenger activity remains present throughout the period, whereas in the event year it shows more frequent and persistent negative deviations from the baseline. Rødbhavn exhibits smaller variations in total vessel presence, but the passenger curve still shows periods of weaker activity during and after the disruption window.



The spatial pattern across the ports is broadly consistent with their position in the maritime network. Aarhus and Copenhagen, which function as larger and more connected nodes, display stronger variability and clearer increases in total vessel presence after the disruption window. Such behaviour is consistent with network adjustment processes, where schedule changes and operational adaptations tend to concentrate at larger hubs. Rødbyhavn, which serves a more specialized and smaller traffic base, shows more limited variation in total vessel presence, although the passenger component remains sensitive to mobility restrictions.



Overall, the first COVID-19 wave in Denmark can be interpreted primarily as a demand-driven disruption with a clear sectoral asymmetry. The diagrams indicate that passenger movements were more directly affected by the restrictions on mobility, while cargo-related maritime activity remained operational and relatively stable throughout the observed period.

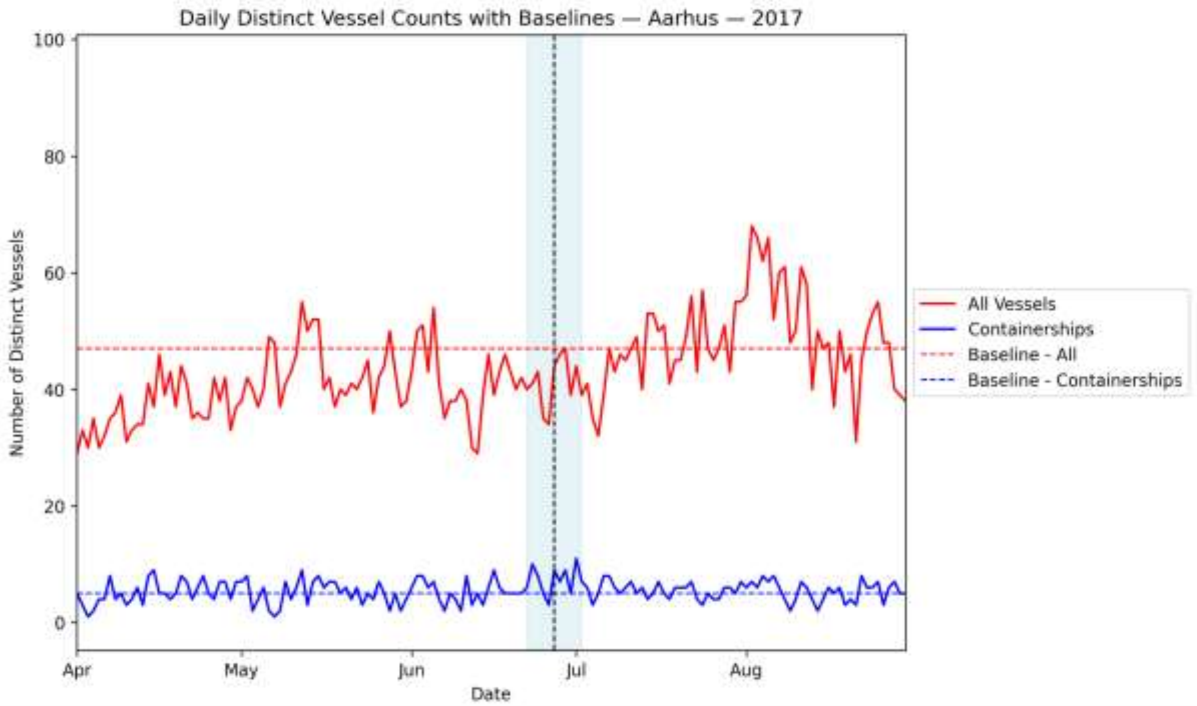


In operational terms, the disruption mechanism appears to operate through reduced passenger demand combined with adjustments in shipping schedules and service rotations. These adjustments generate short-term variability in vessel arrivals and, in some port areas, a temporary increase in the number of vessels present after the initial disruption period, while passenger traffic recovers more slowly.

4.10 NotPetya Cyberattack Denmark Terminals

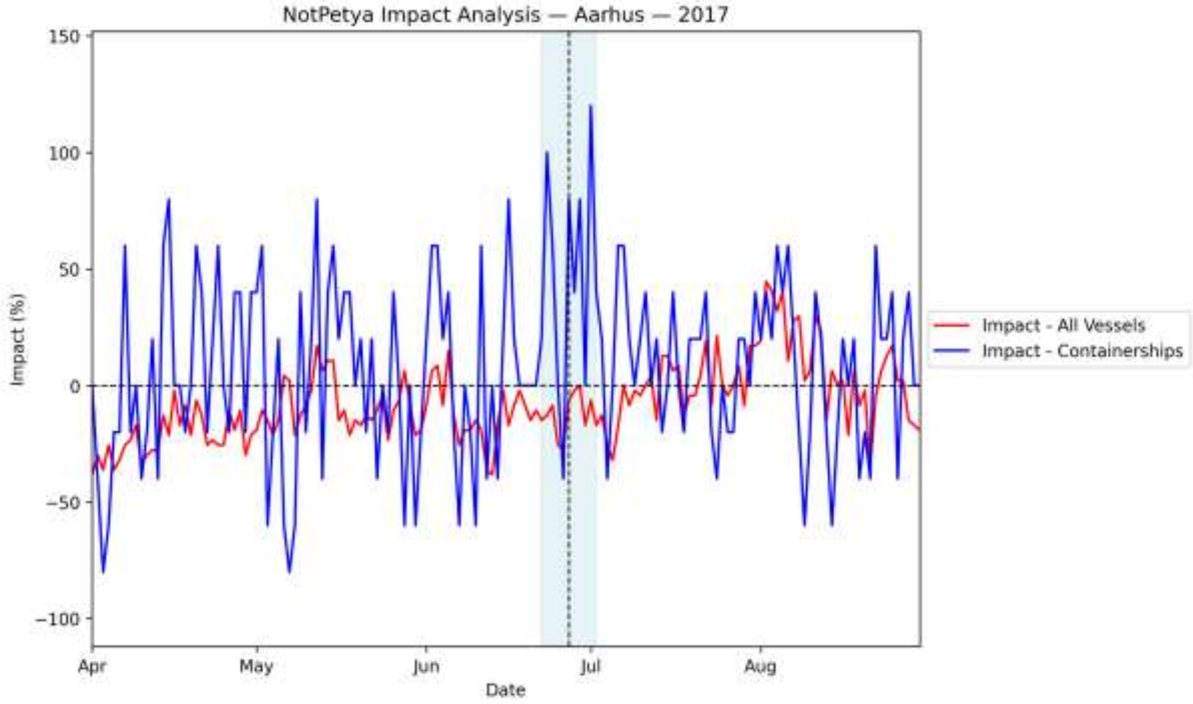
The NotPetya malware outbreak in late June 2017 caused widespread IT outages across Maersk and its APM Terminals network, disrupting digital systems used for booking, cargo documentation, and terminal operations. As reported in international media coverage, several container terminals experienced operational difficulties while systems were restored.

In the Aarhus case, the pre-event traffic pattern suggests a relatively stable operational baseline rather than a system already under stress. The curve in the year-before diagram fluctuates around the baseline level with moderate variability but without any clear downward trend prior to the disruption window. A similar pattern is visible in the containership curve, although this series naturally exhibits stronger short-term fluctuations due to the relatively small number of container vessels operating in the area.



Within the shaded disruption window, the visual evidence does not indicate a sharp collapse in overall port activity. The all-vessels curve remains within the same general range observed earlier in the season, suggesting that vessel presence in the port area continued despite the cyber disruption. At the same time, the containership curve shows short-lived fluctuations around the event period, but these variations appear comparable to the variability already observed outside the disruption window.

The interpretation is further supported by the impact curves. The all-vessels impact curve remains close to the neutral line during the event window and does not display a prolonged negative deviation afterwards. In contrast, the containership impact curve shows pronounced fluctuations throughout the entire observation period, including well before and after the disruption window, indicating that this variability reflects the natural behavior of the container traffic series rather than a clear event-driven shock.Recovery dynamics also appear relatively rapid. Following the disruption window, the all-vessels curve continues without a sustained reduction in activity and later reaches higher levels during the broader summer period. This pattern suggests that the overall vessel presence in the area was not significantly suppressed for an extended period. Any operational frictions generated by the cyber incident were therefore likely absorbed through short-term adjustments rather than through cancellations of port calls.



A comparison with the curves in the year-before and year-after diagrams further supports this interpretation. The event-year traffic pattern remains broadly within the range of variability observed in adjacent years, and the year-after diagram shows continued strong vessel activity during the summer season. This indicates that the disruption did not generate a persistent structural shift in the level of maritime traffic.

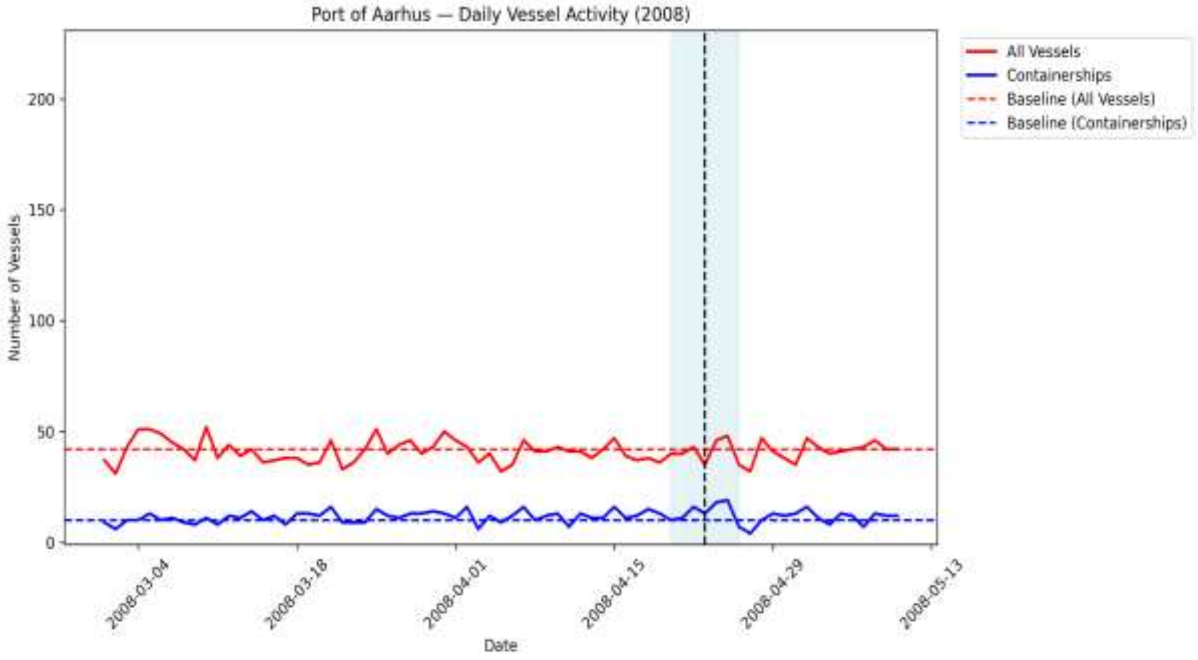
From a network perspective, this outcome is consistent with the nature of cyber disruptions affecting digital coordination systems rather than physical port accessibility. While such incidents can slow cargo processing and reduce operational efficiency within terminals, they do not necessarily prevent vessels from arriving or remaining in the port area. As a result, disruptions of this type may not always produce a clear signal in aggregate AIS-based vessel presence indicators.

Temporary operational volatility rather than a structural disruption of vessel traffic. The evidence suggests that the NotPetya incident generated short-term operational frictions within terminal processes, while the broader maritime traffic pattern in the Aarhus area remained largely stable.

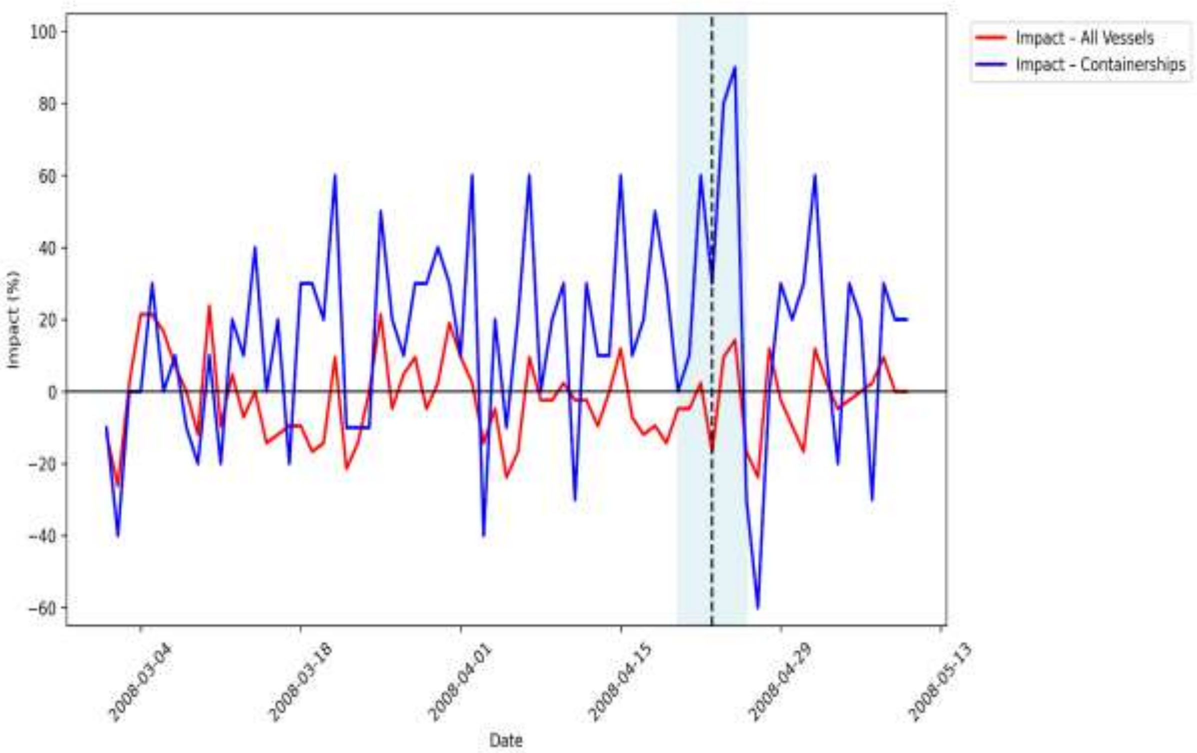
4.11 Labour Dispute Strikes Denmark

In April 2008 Denmark experienced a nationwide labour strike that affected multiple sectors of the economy, including port operations and logistics services, disrupting transportation and cargo handling activities across the country (Reuters, 2008).

The baseline conditions preceding the disruption suggest relatively stable maritime activity in both Danish ports examined in the analysis. In Aarhus, daily vessel traffic during the observation window exhibits moderate variability around a central level close to the long-run baseline. Dispersion indicators remain limited, indicating a stable operational environment prior to the strike. Container ship movements fluctuate within a consistent range relative to the baseline. A similar pattern is visible in Copenhagen, where vessel traffic also varies within a relatively narrow band around its baseline level. Passenger and ferry movements, which dominate Copenhagen's traffic profile, display limited dispersion, indicating a structurally stable passenger transport system prior to the disruption.



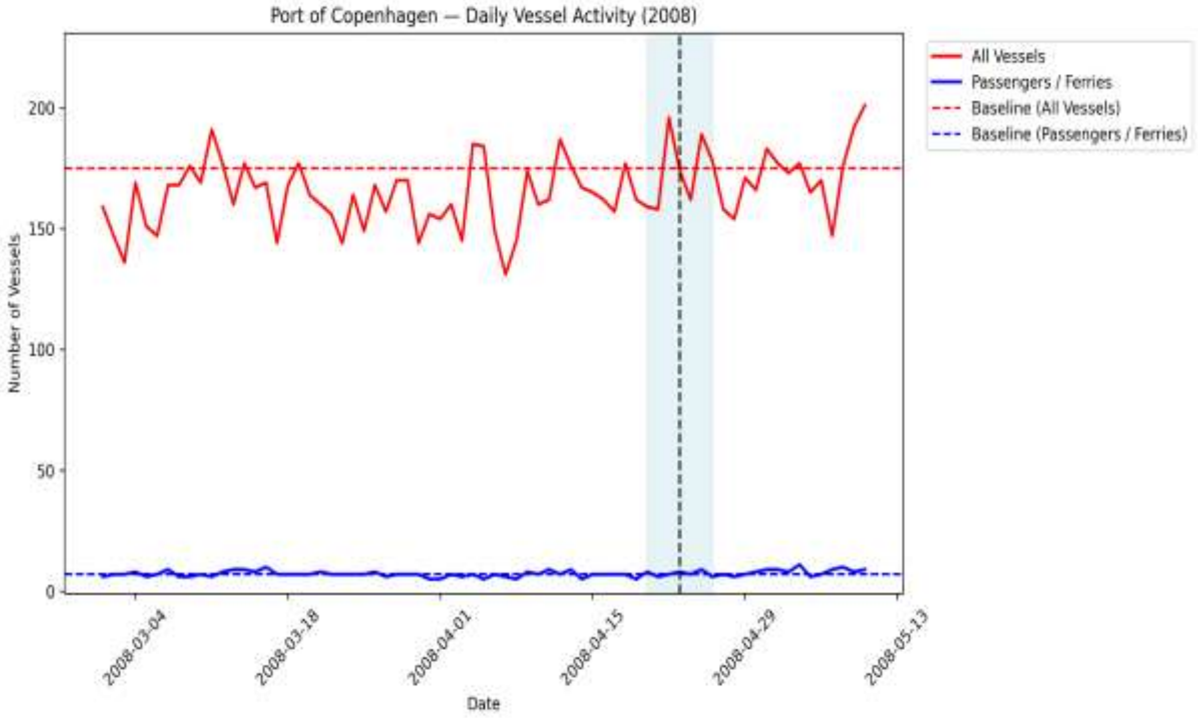
The immediate impact of the strike appears relatively limited in terms of structural changes to vessel activity. In Aarhus, the event window shows short-term volatility around the disruption date but does not reveal a sustained decline in vessel arrivals. Total vessel counts remain broadly aligned with the baseline level, and fluctuations appear consistent with the normal operational variability observed during the baseline period. Container vessel movements exhibit somewhat higher day-to-day variability during the event window, with several short spikes and temporary decreases relative to the baseline. However, these variations remain within the broader range observed in the surrounding periods, suggesting that the strike did not trigger a clear structural break in container traffic.



In Copenhagen the impact is similarly limited. Passenger and ferry activity continues to follow its typical daily pattern throughout the disruption window, with no clear evidence of a systematic decline in traffic volumes. The deviation curves show both positive and negative fluctuations, but these movements remain comparable to the variability observed during the baseline period. Total vessel activity remains close to its usual range, indicating that port activity continued despite the nationwide labour dispute.

The recovery pattern further supports the interpretation of limited structural disruption. In Aarhus, vessel counts remain relatively stable after the event window, and the time series continues within its typical variability range without prolonged deviations. Container traffic continues to fluctuate within the levels observed before the disruption, indicating that shipping services were not significantly rerouted or suspended. In Copenhagen, both passenger and total vessel traffic maintain a steady trajectory after the disruption, with no persistent reduction in activity levels.

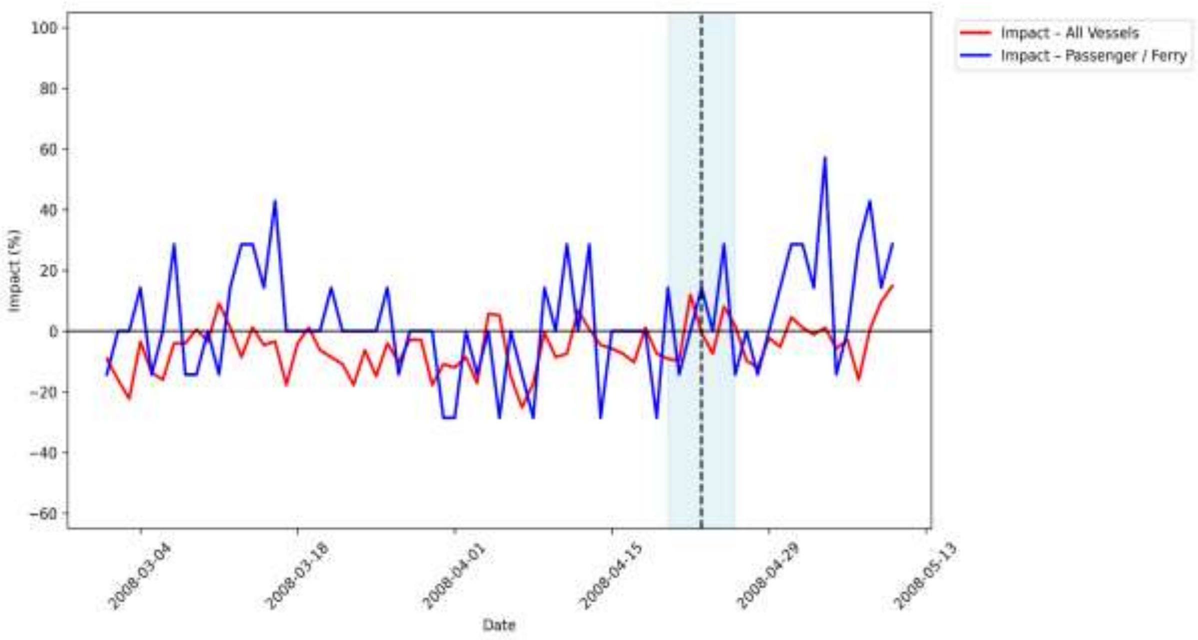
Comparison with the year-before and year-after periods provides additional context for interpreting the disruption. The pre-event year shows broadly similar variability patterns in both ports, reinforcing the interpretation that the fluctuations observed during the strike period fall within the normal operational range.



In the year after the strike, vessel activity in Aarhus showed somewhat higher traffic levels compared with the surrounding periods, suggesting broader changes in maritime activity rather than disruption-related recovery. Copenhagen exhibits comparable stability across all three periods, with passenger traffic remaining relatively consistent over time.

From a spatial perspective, the limited traffic-level impact of the nationwide strike may be linked to the operational structure of Danish maritime transport. Aarhus functions primarily as a container gateway integrated into scheduled liner networks serving Northern Europe. Such services typically maintain schedule reliability through operational adjustments, including minor delays or rescheduling rather than cancelling port calls. Copenhagen, in contrast, is strongly oriented toward passenger ferry services linking Denmark with neighboring countries. These routes operate on regular schedules and may therefore continue operating even during short-term labour disturbances unless terminal operations are completely halted.

Overall, the empirical evidence suggests that the 2008 nationwide strikes in Denmark generated temporary operational volatility rather than a structural disruption in maritime traffic flows. Vessel activity in both ports remained broadly within the historical variability range, and deviations during the event window were short-lived. The disruption therefore appears to represent temporary volatility rather than a systemic breakdown of port connectivity.



From a disruption-mechanism perspective, the strikes likely affected specific port services such as cargo handling, labour availability, or logistics coordination rather than maritime navigation itself. Shipping lines appear to have absorbed these operational frictions through short-term scheduling adjustments, allowing vessel flows to continue with limited interruption. Consequently, the disruption manifested primarily as short-term variability in daily vessel presence rather than a persistent structural decline in port activity.

4.12 Synthesis of Findings and Comparative Assessment

The completion of the empirical analysis across the twelve case studies allows for a comparative evaluation of how different types of disruptions influence maritime traffic systems. By examining changes in vessel presence across multiple regions and disruption categories, this section synthesizes the main findings and identifies the dominant mechanisms through which disruptions affect maritime transport networks. The objective is to determine which types of events generate the most significant operational disturbances, how long these effects tend to persist, and how variations in vessel traffic relate to broader economic consequences for maritime logistics and port operations.

4.12.1 Taxonomy of Disruption Mechanisms

The comparative analysis indicates that disruptions affecting maritime systems tend to follow three broad operational patterns.

The first pattern corresponds to congestion accumulation. In this case, vessel presence increases within the maritime area surrounding a port because ships are unable to enter or exit the port system at their normal pace. This pattern can be observed in situations where port capacity is temporarily reduced or access to port infrastructure is constrained. The collapse of the Baltimore bridge and the congestion episodes observed in the Los Angeles-Long Beach port complex provide clear examples of this mechanism. Rather than reflecting an increase in shipping demand, the higher concentration of vessels indicates that ships remain longer within port approaches while waiting for access or improved terminal productivity. The economic implications of this pattern are particularly significant, as delays accumulate and operational costs increase throughout the wider shipping network.

A second mechanism can be described as a structural adjustment or rerouting pattern. This occurs when disruptions alter the spatial structure of maritime trade flows. Geopolitical events such as the Russia/Ukraine conflict or the Nord Stream pipeline explosions illustrate this mechanism. In these situations, vessel activity does not simply return to its previous level after the disruption. Instead, traffic patterns gradually stabilize at new levels that reflect adjustments in trade routes, commodity flows, or regional supply chains. For example, shifts in global energy markets led to increased tanker activity in U.S. export regions, while traffic in certain parts of the Baltic Sea declined slightly due to localized route adjustments. These changes are typically associated with longer-term economic effects, including modifications in shipping routes and adjustments in global logistics networks.

The third pattern corresponds to temporary operational volatility. In this situation, vessel traffic displays short-term fluctuations but returns relatively quickly to its normal operational pattern. Events such as the NotPetya cyberattack, Storm Malik, and the Danish labour strikes illustrate this type of response. These disruptions introduce temporary operational difficulties but do not fundamentally restrict port access or alter the structure of maritime trade flows. As a result, shipping operators are generally able to adapt through scheduling adjustments, operational coordination, or temporary procedural changes. While such events may generate additional operational costs in the short term, their long-term impact on vessel traffic patterns tends to remain limited.

4.12.2 Comparative Analysis: Duration and Intensity of Disruption

The comparative assessment also reveals important differences between the intensity and the duration of maritime disruptions.

Events that directly affect physical infrastructure or navigational access tend to produce the most immediate operational disturbances. Natural disasters and major infrastructure failures can disrupt port operations suddenly by restricting access to critical waterways or port facilities. In such cases, vessel traffic either declines abruptly due to temporary closures or increases locally as ships accumulate in surrounding maritime areas while waiting for access to be restored.

In contrast, the longest-lasting disruptions are typically associated with broader economic or geopolitical developments. Events such as the COVID-19 pandemic or the reconfiguration of global energy trade following geopolitical tensions influence maritime activity over longer periods. Rather than producing a short operational interruption, these shocks modify global trade patterns and shipping demand. Vessel traffic therefore stabilizes at new levels reflecting structural adjustments in supply chains and international trade flows.

Technological disruptions and short labour disputes generally display the fastest recovery patterns. Events affecting digital infrastructure or administrative processes may create temporary operational complications but rarely compromise the physical capacity of ports or shipping routes. Consequently, maritime traffic often continues with limited interruption and gradually returns to its typical operational rhythm once the disturbance has passed.

4.12.3 Economic Interpretation of Observed Traffic Changes

Variations in vessel presence also provide useful insight into the broader economic implications of maritime disruptions. Three principal economic mechanisms emerge from the comparative analysis.

First, disruptions may lead to direct revenue losses when maritime transport demand declines. This pattern is particularly visible in the passenger transport sector during the COVID-19 pandemic, where mobility restrictions significantly reduced ferry and passenger vessel activity in several regions. In these cases, reduced vessel presence reflects lower demand for maritime transport services and therefore reduced revenue for operators. Second, disruptions may generate higher operational costs even when overall vessel traffic remains relatively stable. Cyber incidents such as the NotPetya attack illustrate this mechanism. Although vessel movements continued, terminal operators and shipping companies faced operational difficulties related to manual procedures, slower documentation processes, and reduced logistical efficiency.

Third, disruptions may create systemic congestion costs within maritime logistics networks. When infrastructure capacity is restricted or operational productivity declines, vessels accumulate in port approaches or nearby maritime areas. This congestion generates cascading delays across shipping schedules, increases waiting times, and raises operational costs throughout the global transport system.Taken together, these patterns demonstrate that changes in vessel presence provide a useful indicator of both operational disruptions and their broader economic consequences for maritime logistics systems.

4.12.4 Comparative Evaluation of Disruption Types

The synthesis of findings across all cases allows for a general comparison of disruption categories in terms of their typical impact intensity, duration, and economic implications.

Disruption Type	**Impact Intensity**	**Typical Duration**	**Dominant Economic Effect**
Natural Disasters	Very High	Short to Medium	Delay costs and infrastructure repair
Geopolitical Shocks	Moderate	Long	Trade rerouting and higher transport costs
COVID-19 (Cargo Networks)	Moderate	Long	Supply chain instability and congestion
COVID-19 (Passenger Sector)	High	Very Long	Direct revenue loss
Cyber-attacks	Low	Very Short	Operational management costs
Maritime Accidents	Very High	Medium	Congestion and capital immobilization
Labour Disputes	Moderate	Medium	Waiting costs and schedule disruptions

Author's Table 4.1 summarizes the comparative findings derived from the disruption case studies and the AIS traffic analysis.

Overall, the results indicate that maritime transport systems display considerable resilience to short-term operational disturbances such as cyber incidents, weather events, and limited labour disputes. However, disruptions affecting critical infrastructure, global trade patterns, or energy markets tend to produce more substantial and persistent changes in maritime traffic dynamics.

Finally, the analysis highlights that the scale of disruption impacts depends not only on the triggering event itself but also on the structural role of the affected ports within the global shipping network. Major maritime hubs and key transport corridors tend to amplify the systemic consequences of disruptions, while more localized disturbances can often be absorbed through operational adjustments and network flexibility.

5. Conclusions

5.1 Discussion of Findings

The empirical investigation of the twelve disruption cases provides important insights into how different types of shocks influence maritime traffic systems. By analysing vessel presence using AIS-based traffic indicators, the study identifies clear differences in the way disruptions affect maritime activity in terms of their intensity, duration, and spatial manifestation.

The results indicate that disruptions affecting physical infrastructure generate the most immediate operational impacts on maritime systems. When port access or navigational channels are temporarily restricted, maritime traffic is directly affected because vessels are unable to enter or leave port areas under normal conditions. Such disruptions reduce the effective capacity of port systems and may lead either to temporary declines in vessel activity or to the accumulation of vessels in surrounding maritime areas while ships wait for access to be restored.

In contrast, geopolitical and macroeconomic disruptions tend to produce more gradual but longer-lasting adjustments in maritime traffic patterns. These events often alter global trade flows and commodity movements rather than directly interrupting port operations. As a result, vessel activity may stabilize at new levels that reflect broader changes in trade routes, supply chains, and shipping demand. This type of disruption therefore represents a structural adjustment within the maritime transport network rather than a short-term operational disturbance.

The analysis of the COVID-19 pandemic further illustrates the complex nature of economic shocks in maritime transport. Different segments of maritime activity respond in different ways depending on the underlying demand structure. Passenger-related traffic experienced a significant decline in several regions due to mobility restrictions, while cargo-related vessel movements remained comparatively resilient and in some cases even increased as global supply chains adjusted to shifting consumption patterns.

The study also highlights the adaptive capacity of maritime transport networks in response to technological and operational disruptions. Events such as cyber incidents, severe weather disturbances, and localized labour disputes introduced temporary operational volatility but did not lead to long-term structural changes in vessel traffic patterns. Shipping operators and port systems appear capable of absorbing these disturbances through operational adjustments, schedule modifications, and the inherent flexibility of maritime logistics networks.

Another important observation concerns the role of port hierarchy within global shipping systems. Major hub ports tend to experience congestion accumulation during disruptions rather than a complete collapse in maritime activity. Because these ports function as critical nodes within global logistics chains, vessel arrivals continue even when port operations are temporarily constrained. This often results in the spatial concentration of vessels in nearby maritime areas while operational capacity is restored.

Taken together, the findings suggest that maritime disruptions can be broadly understood through four functional response patterns: infrastructure capacity shocks, demand-driven disruptions, structural trade rerouting, and temporary operational volatility. These categories reflect the different mechanisms through which disruptions propagate within maritime transport networks.

5.2 Practical Implications

The findings of this study have several implications for maritime transport management and port resilience planning.

First, the results underline the importance of maintaining operational redundancy in critical maritime infrastructure. Ports that serve as major hubs within global shipping networks are particularly vulnerable to congestion accumulation when disruptions occur. Strengthening contingency planning, improving traffic management systems, and enhancing coordination between port authorities and shipping lines can help reduce the operational consequences of such events.

Second, the analysis demonstrates the usefulness of AIS-based monitoring tools for identifying disruption patterns in maritime systems. Observing changes in vessel presence can provide early indications of abnormal traffic conditions, congestion buildup, or traffic redistribution following disruptive events. Such information may assist port authorities and maritime planners in responding more effectively to emerging operational challenges.

Finally, the results emphasize the need for integrated risk management strategies that take into account both local operational vulnerabilities and broader geopolitical or economic developments. While some disruptions originate from localized infrastructure failures, others stem from systemic changes in global trade patterns that require longer-term strategic adaptation by maritime stakeholders.

5.3 Limitations of the Study

Despite the insights provided by this analysis, several limitations should be acknowledged.

First, the study relies primarily on AIS-based vessel presence indicators. Although these indicators provide valuable information about the spatial distribution of maritime traffic, they do not directly capture cargo volumes, terminal productivity, or port throughput. Consequently, certain disruptions that primarily affect administrative processes or cargo handling operations may not be fully reflected in vessel traffic patterns.

Second, the spatial boundaries used in the analysis are defined through predefined geographic observation areas. While this approach allows for consistent comparison across different case studies, it may not fully capture traffic adjustments that occur slightly outside the defined study zones.

Third, the empirical analysis focuses on selected case studies in the United States and Denmark. Although these cases represent a diverse range of disruption types, the findings may not necessarily be directly applicable to all maritime regions or port systems. Different institutional environments, infrastructure configurations, and trade structures may produce different responses to similar disruptions.

5.4 Directions for Future Research

Future research could expand the analytical framework developed in this study in several directions.

One potential extension would involve integrating AIS vessel presence data with additional datasets, such as port call records, cargo throughput statistics, and terminal performance indicators. Combining multiple data sources could provide a more comprehensive understanding of how disruptions influence both vessel movements and cargo handling operations within ports.

Further studies could also examine a broader set of disruption events across different geographical regions in order to evaluate whether similar traffic response patterns emerge in other maritime systems.

Finally, future research could explore the development of early-warning systems for maritime disruptions. By applying statistical anomaly detection techniques to AIS vessel traffic data, it may be possible to identify abnormal traffic conditions in near real time and provide early indications of emerging disruptions in maritime networks.

5.5 Final Conclusions

This study demonstrates that disruptions in maritime transport systems vary significantly in their intensity, duration, and systemic consequences depending on the nature of the underlying event.

By applying an AIS-based analytical framework to a series of disruption case studies, the research identifies distinct patterns in the way maritime traffic responds to infrastructure failures, economic shocks, geopolitical developments, and operational disturbances. While certain disruptions produce severe short-term operational impacts, the global maritime system also displays a strong capacity to adapt through rerouting, scheduling adjustments, and network flexibility.

Overall, the findings contribute to a better understanding of disruption dynamics in maritime transport and highlight the importance of resilient infrastructure, adaptive logistics systems, and effective monitoring tools in maintaining the stability of global shipping networks.

The analytical framework developed in this study also provides a foundation for future research on maritime disruption analysis and the resilience of international shipping systems in an increasingly uncertain global environment.

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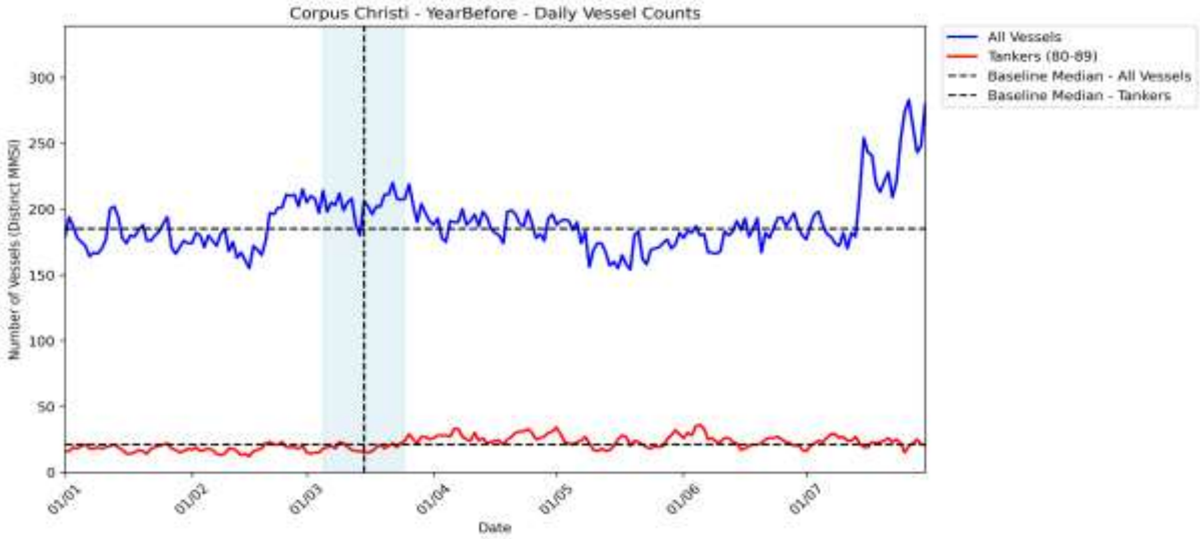
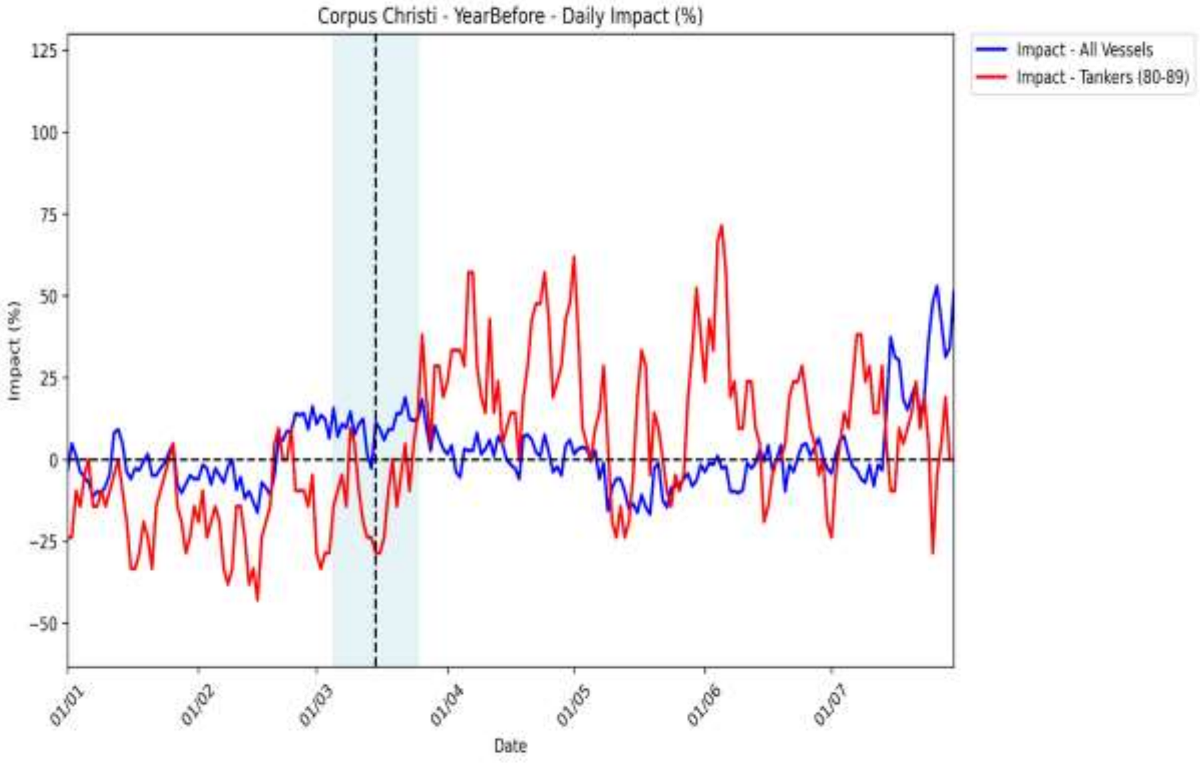
Appendix A - Additional Diagrams (USA Cases)

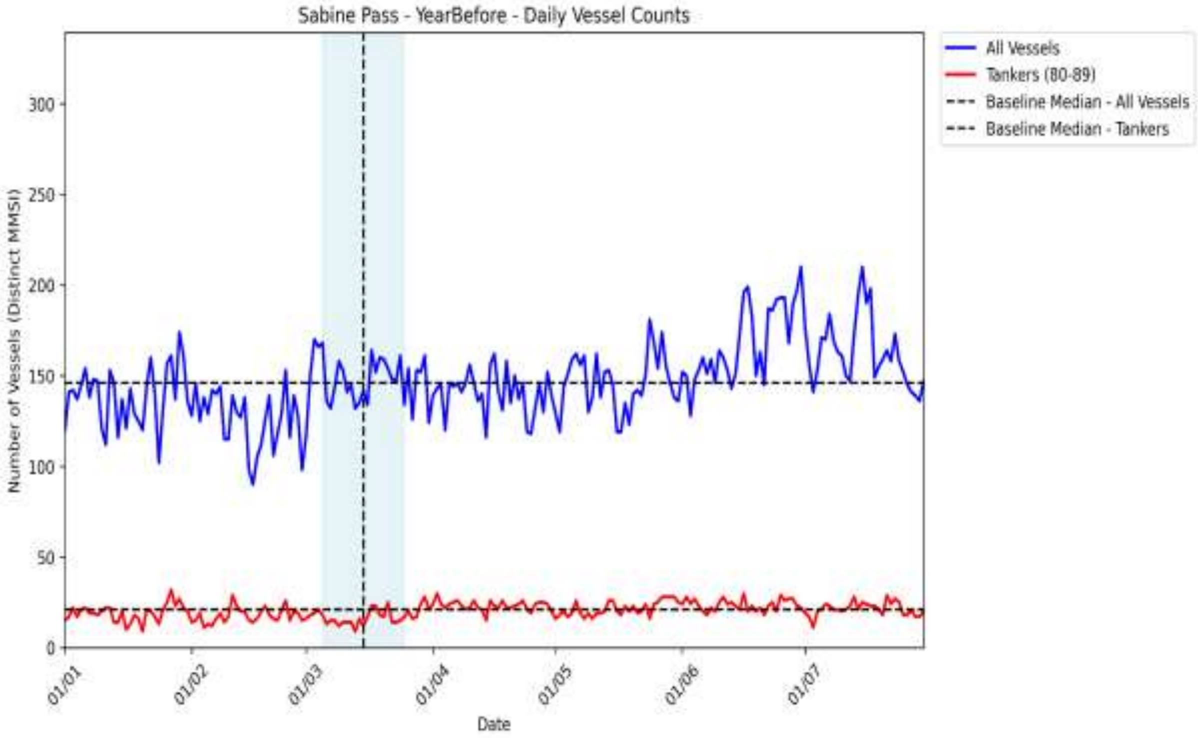
4.1 Natural Disruption USA

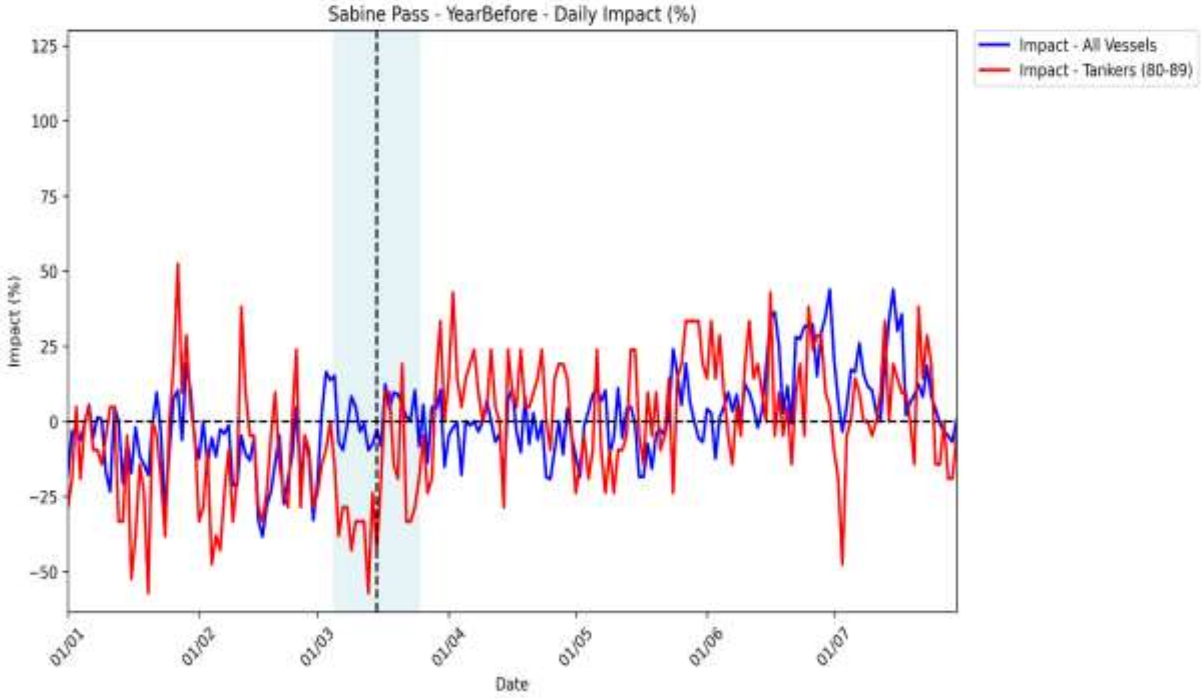
No year before or after because of the sure results about this case.

4.2 Geopolitical Shock and Port Traffic Realignment USA






Sabine Pass - YearBefore - Daily Vessel Counts
All Vessels
Tankers (80-89)
Baseline Median - All Vessels
Baseline Median - Tankers
Number of Vessels (Distinct MMSI)
0
50
100
150
200
250
300
01/01
01/02
01/03
01/04
01/05
01/06
01/07
Date


Sabine Pass - YearBefore - Daily Impact (%)
Impact - All Vessels
Impact - Tankers (80-89)
Impact (%)
125
100
75
50
25
0
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01/02
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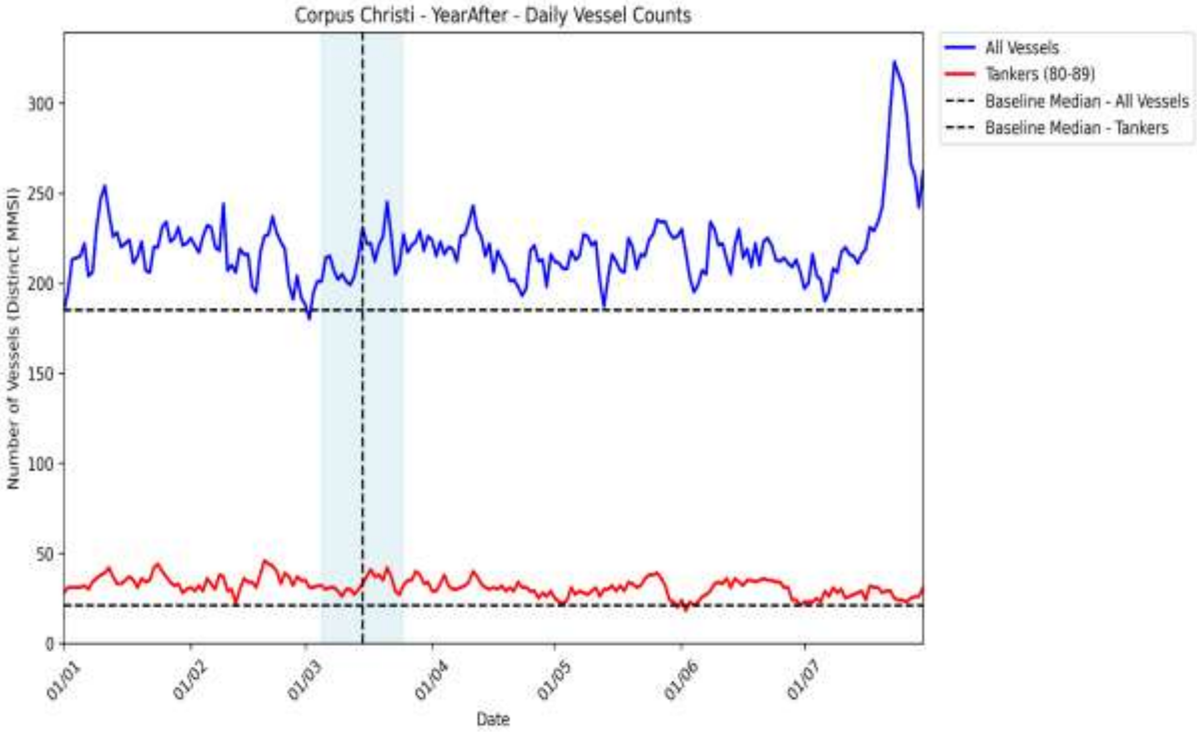
01/05
01/06
01/07
Date


Corpus Christi - YearAfter - Daily Vessel Counts
Number of Vessels (Distinct MMSI)
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150
200
250
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01/01
01/02
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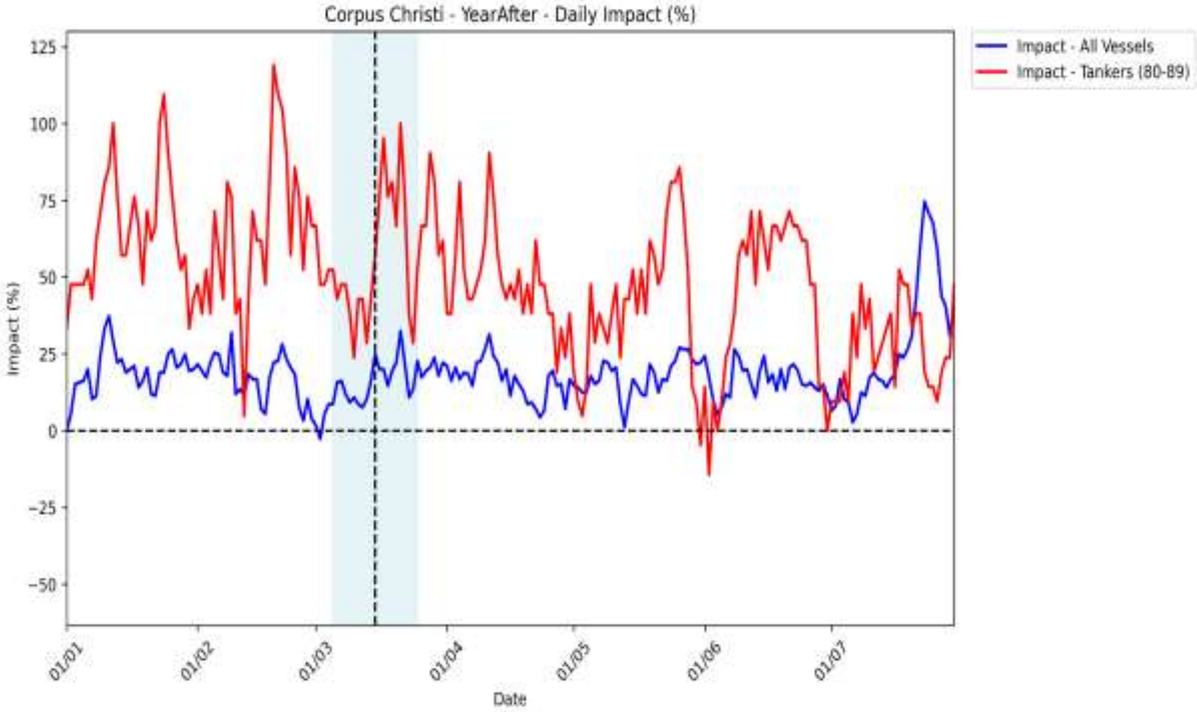
01/06
01/07
Date
All Vessels
Tankers (80-89)
Baseline Median - All Vessels
Baseline Median - Tankers


Corpus Christi - YearAfter - Daily Impact (%)
Impact (%)
125
100
75
50
25
0
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01/06
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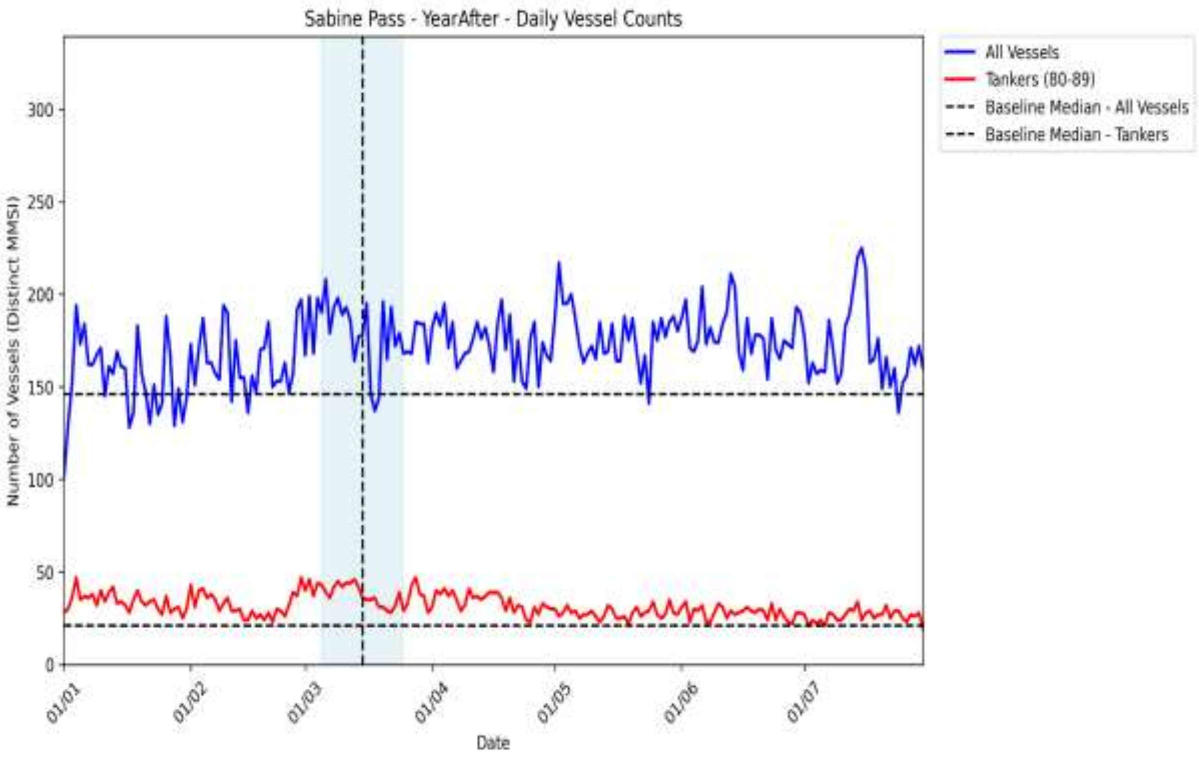
Date
Impact - All Vessels
Impact - Tankers (80-89)


Sabine Pass - YearAfter - Daily Vessel Counts
Number of Vessels (Distinct MMSI)
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100
150
200
250
300
01/01
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01/03
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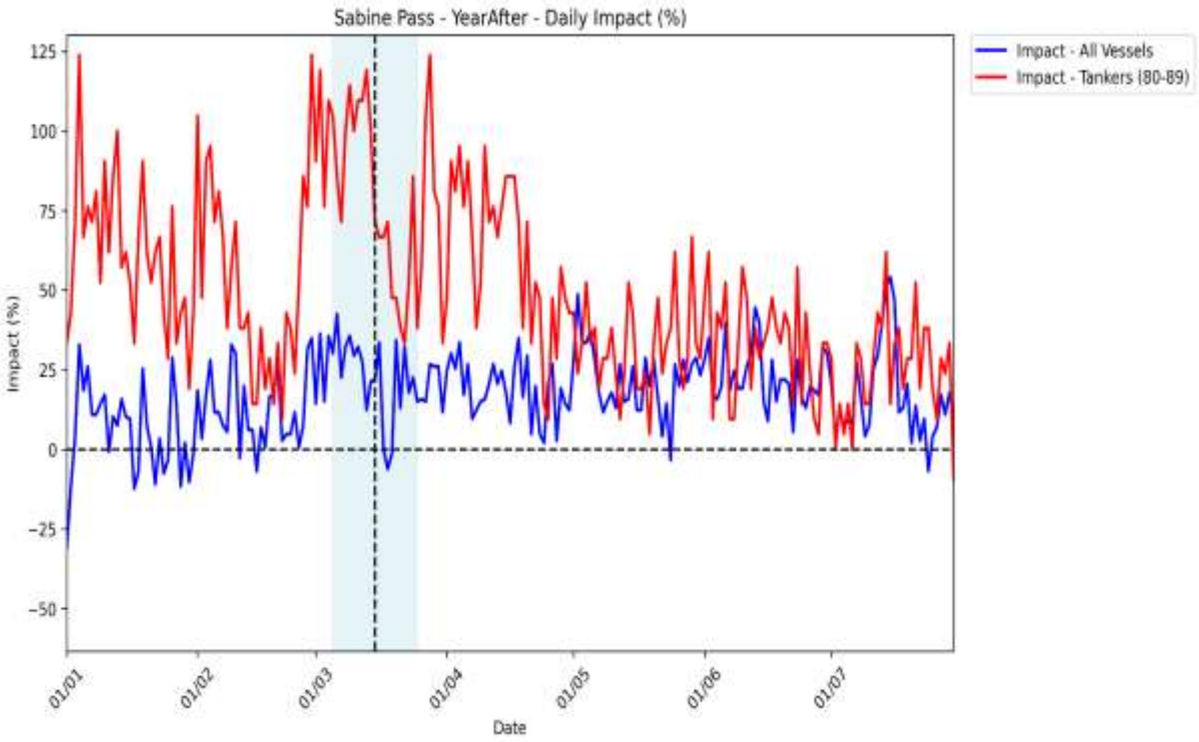
01/07
Date
All Vessels
Tankers (80-89)
Baseline Median - All Vessels
Baseline Median - Tankers


Sabine Pass - YearAfter - Daily Impact (%)
Impact (%)
125
100
75
50
25
0
-25
-50
01/01
01/02
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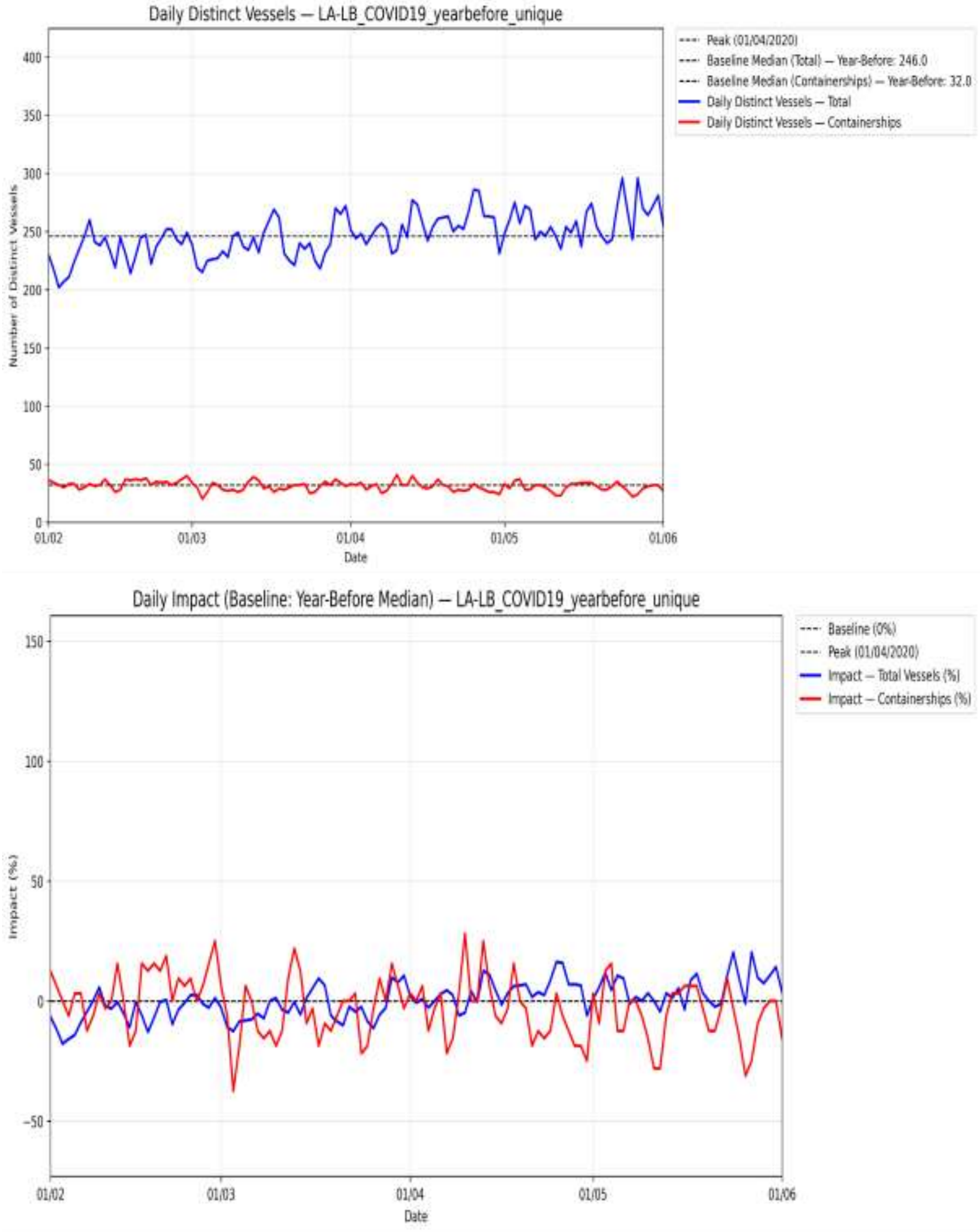
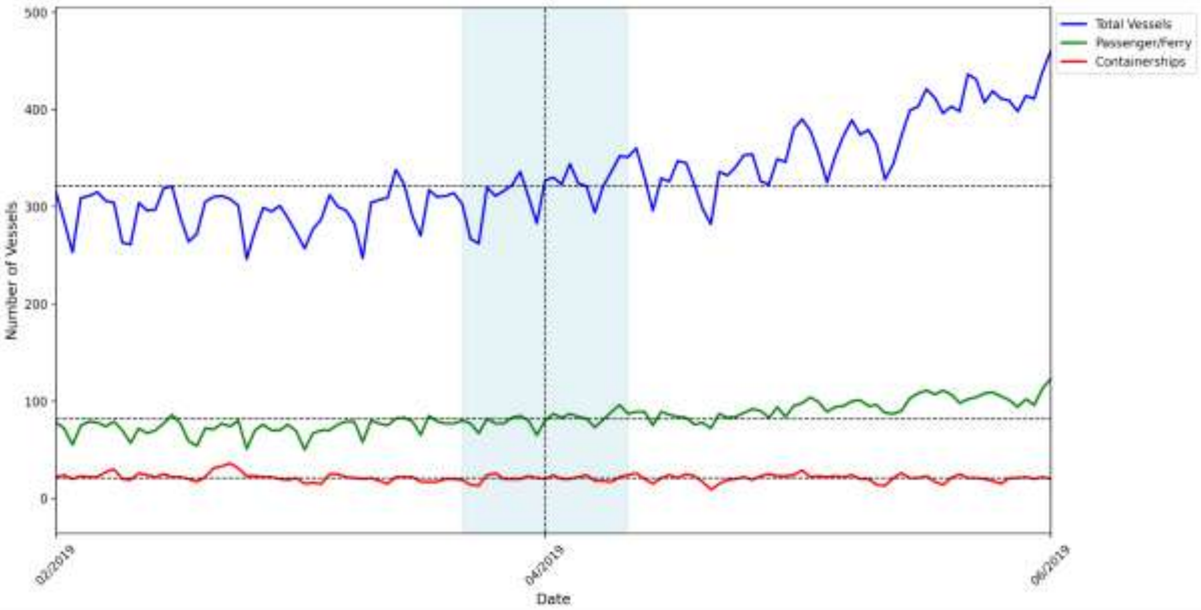
Date
Impact - All Vessels
Impact - Tankers (80-89)

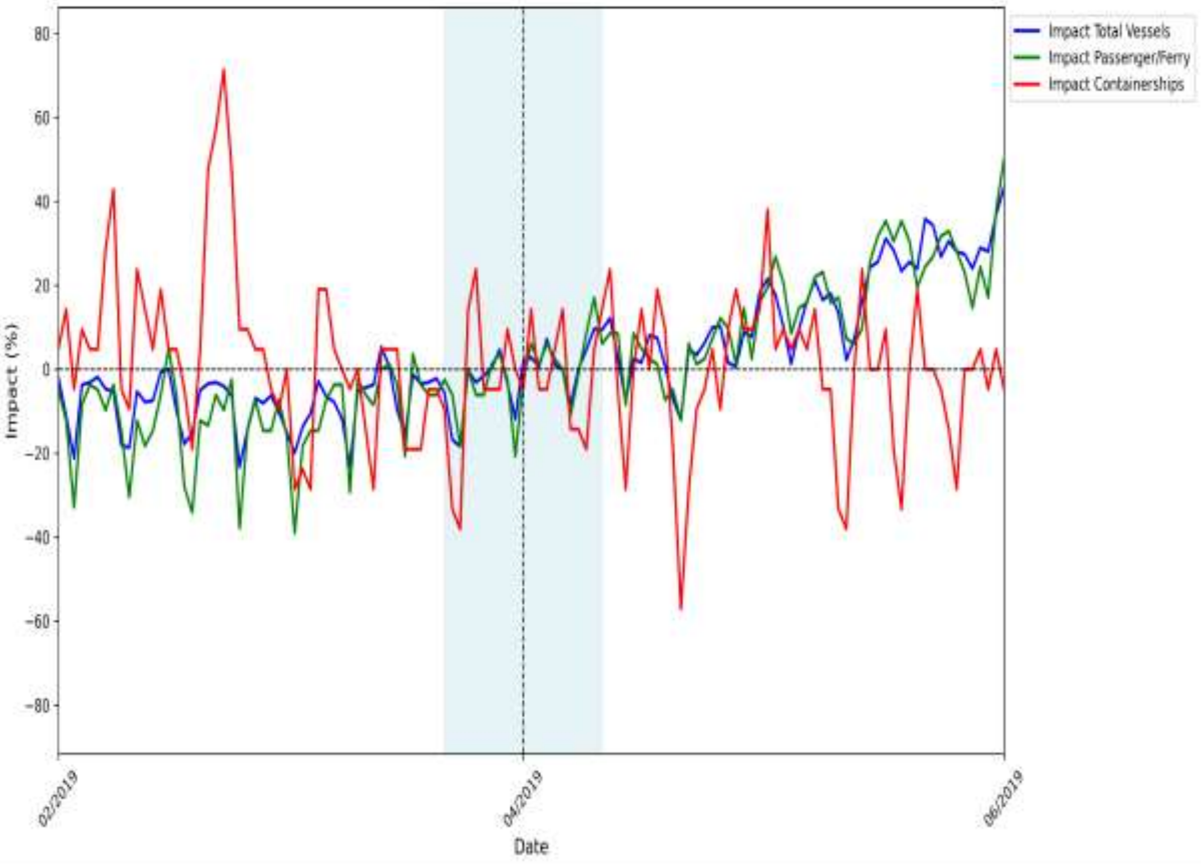
4.3 Covid -19 First Wave USA

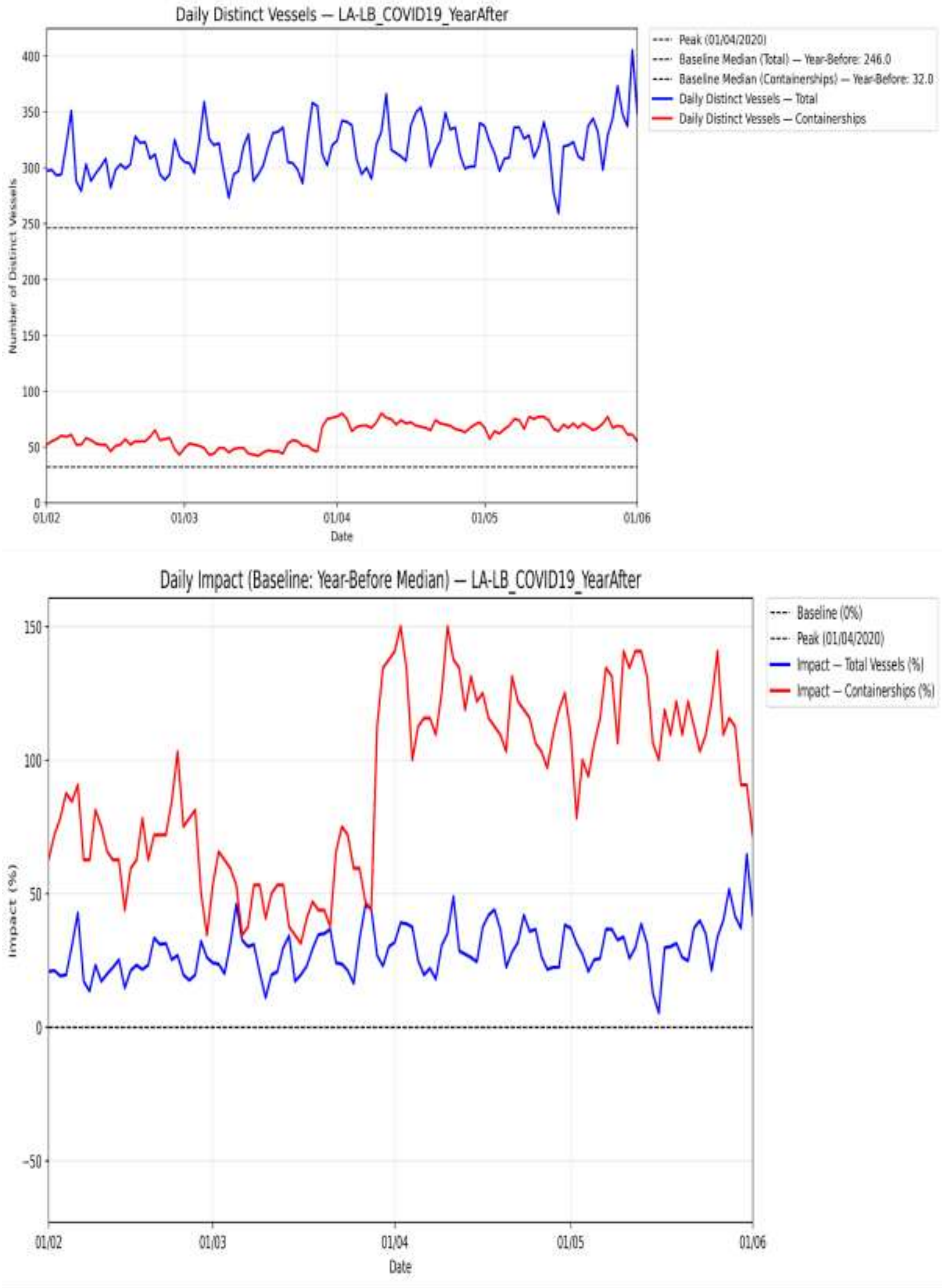


Daily Distinct Vessels Ny/NJ Covid 19 Year Before

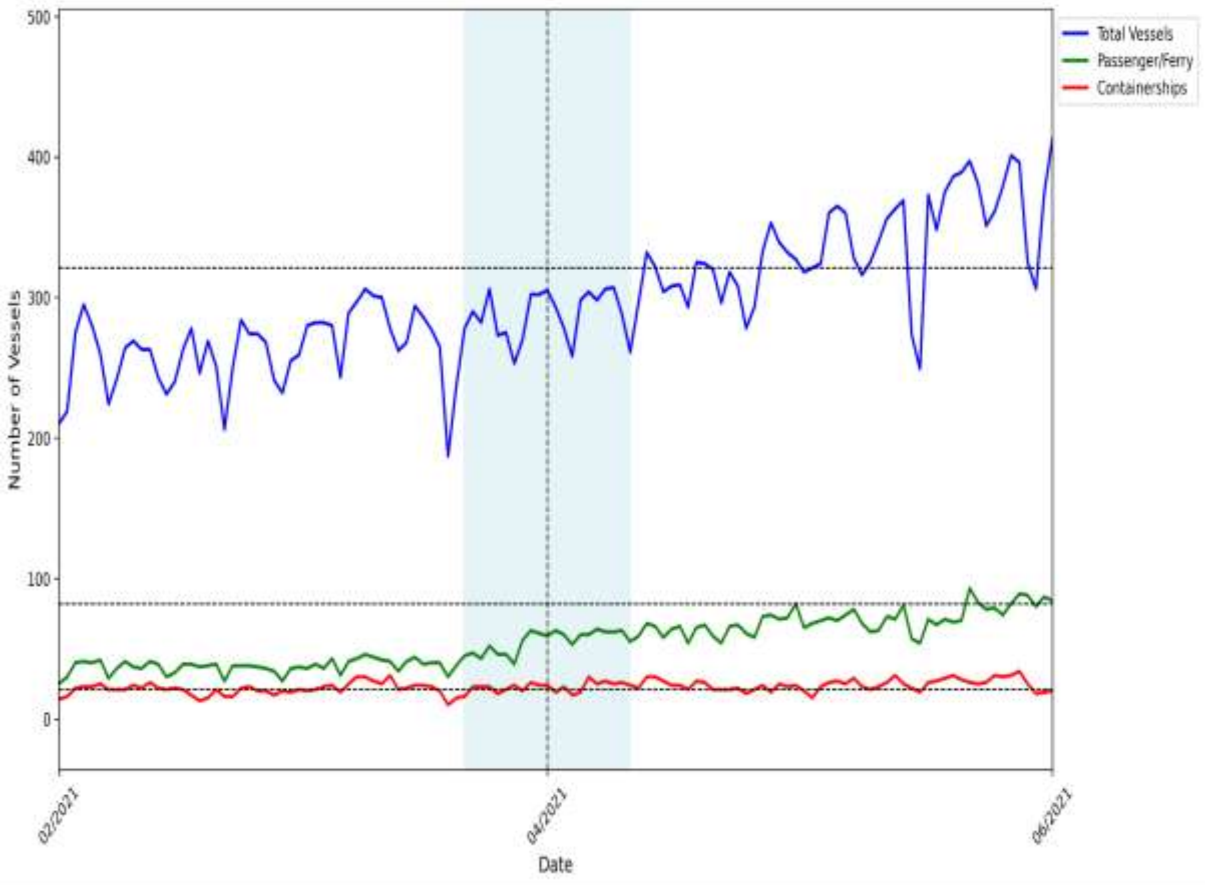


Daily Impact Vessels Ny/NJ Covid 19 Year Before

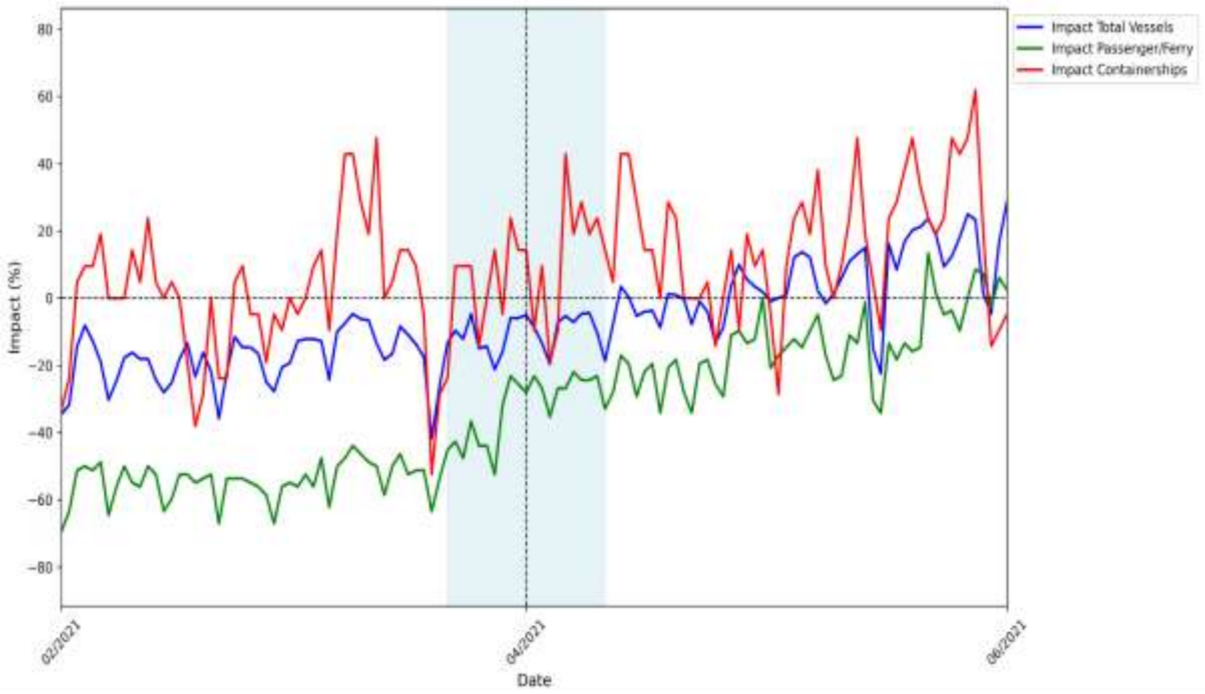




Daily Impact Vessels Ny/NJ Covid 19 Year After

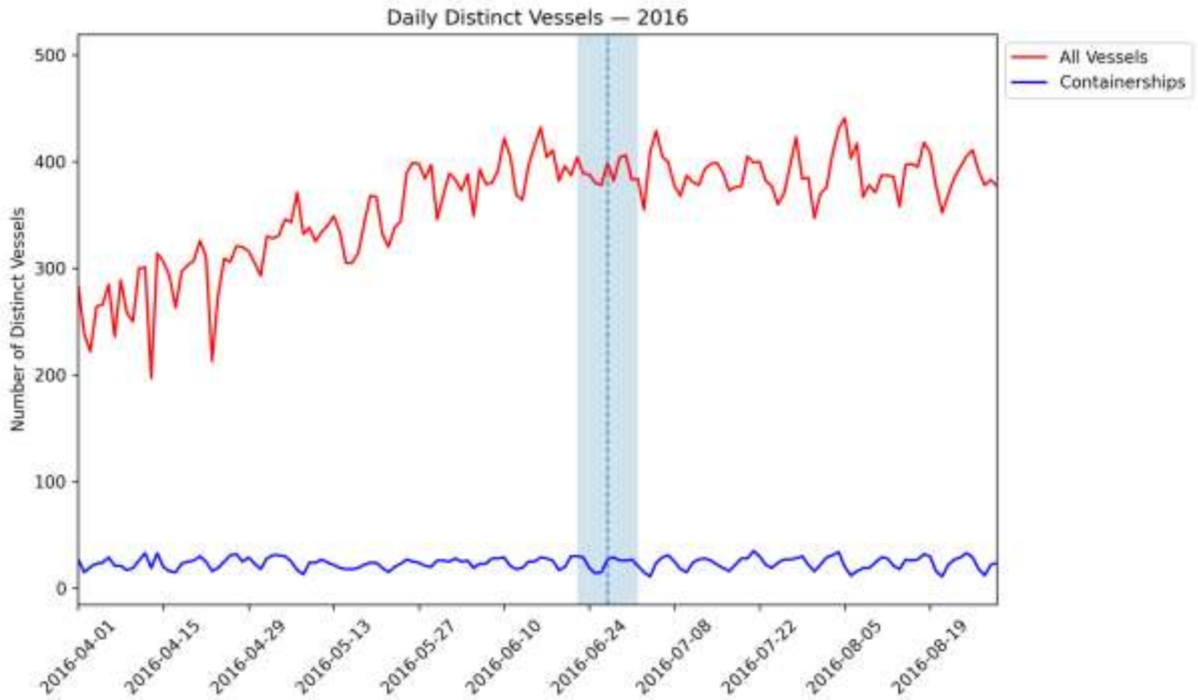


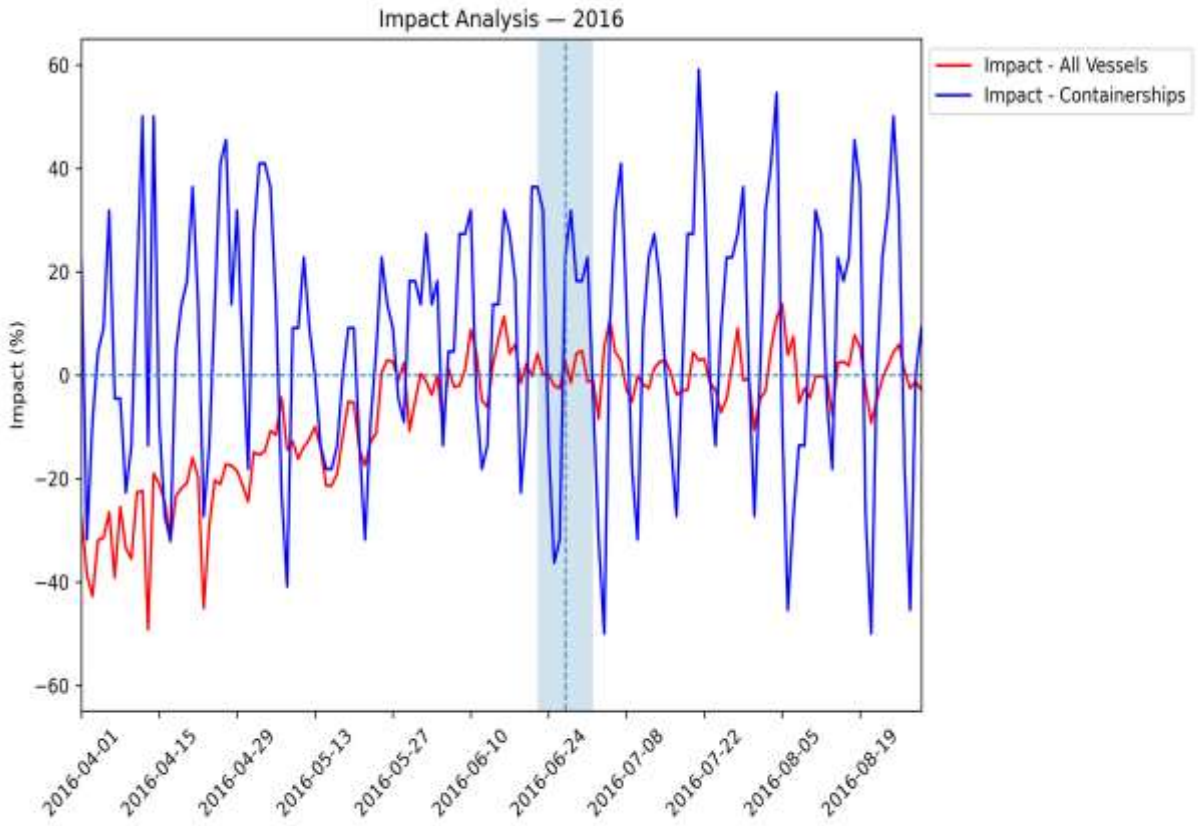
Daily Impact Vessels Ny/NJ Covid 19 Year After

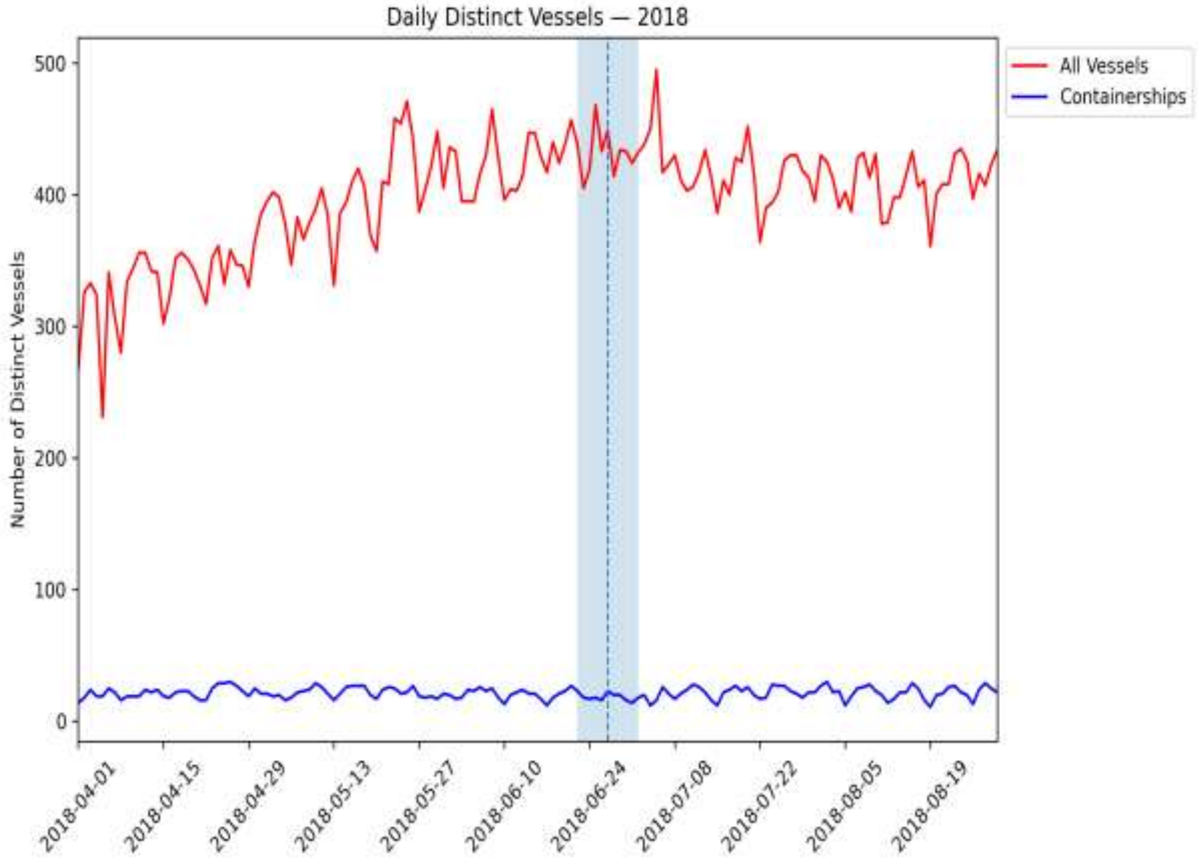


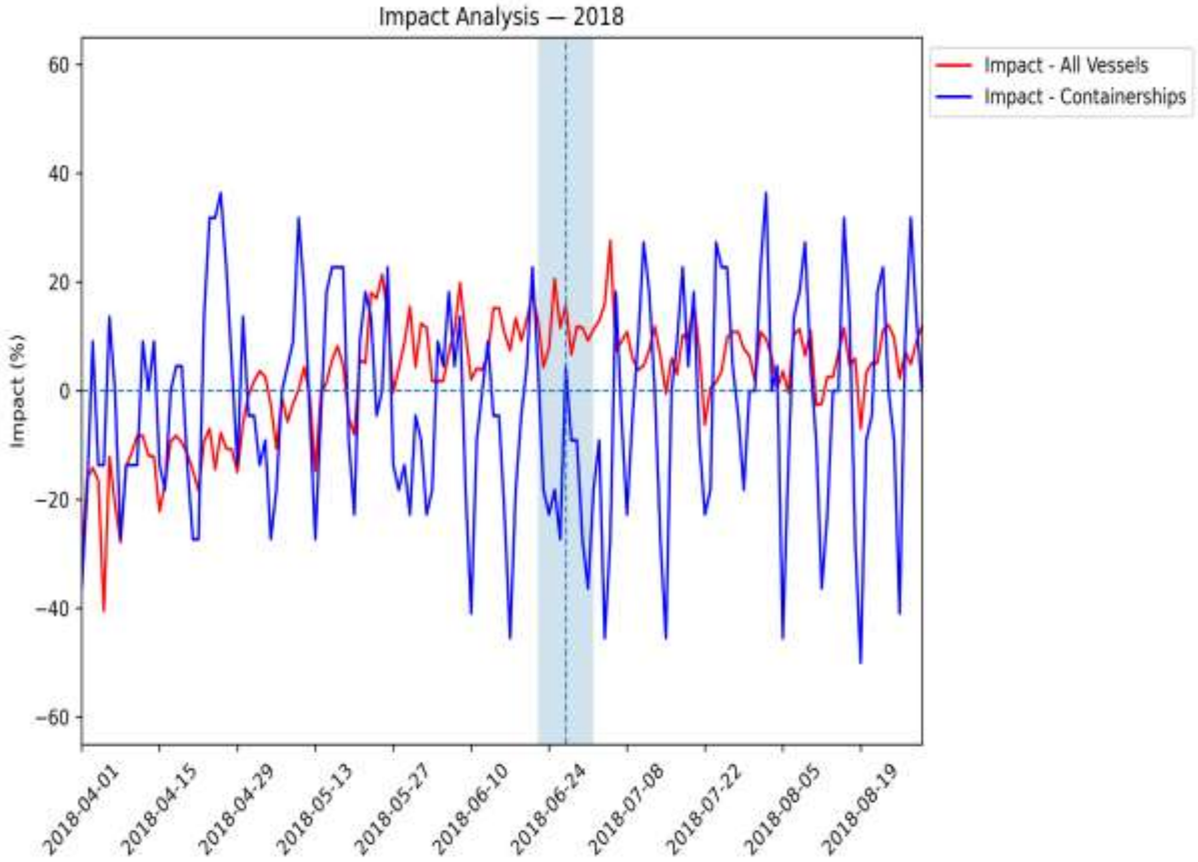
4.4 NotPetya Cyberattack USA Terminals

Port Elizabeth New York

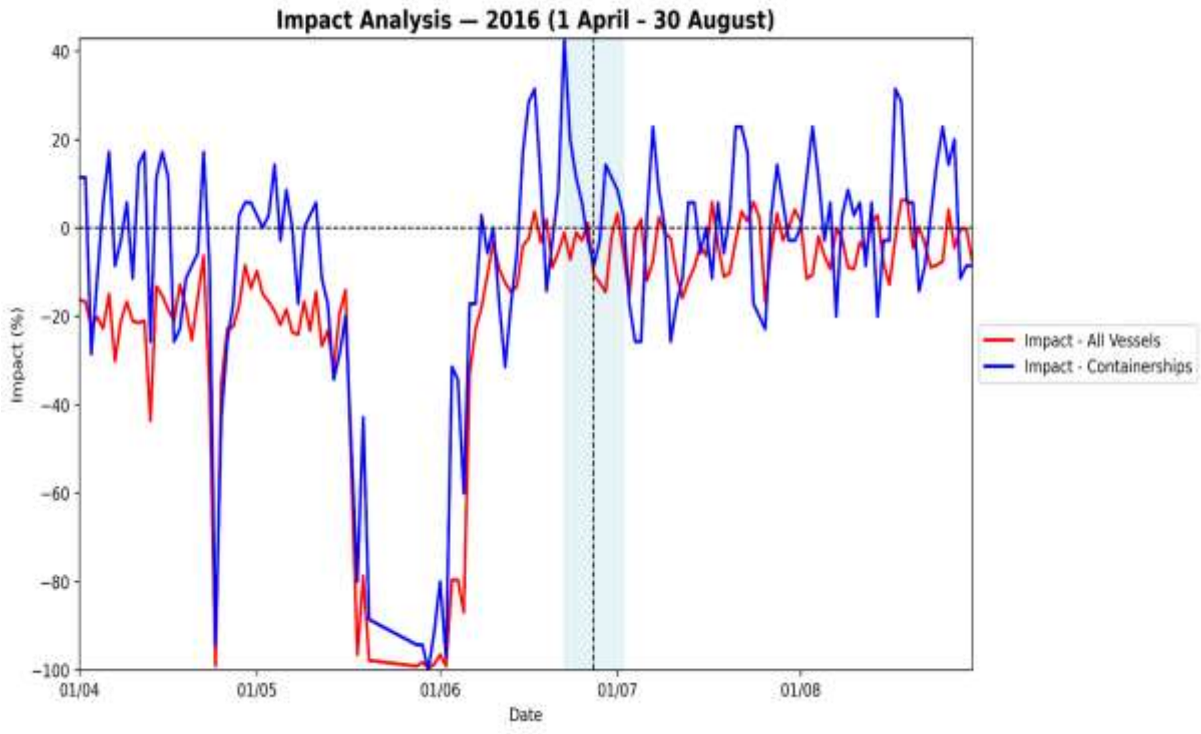


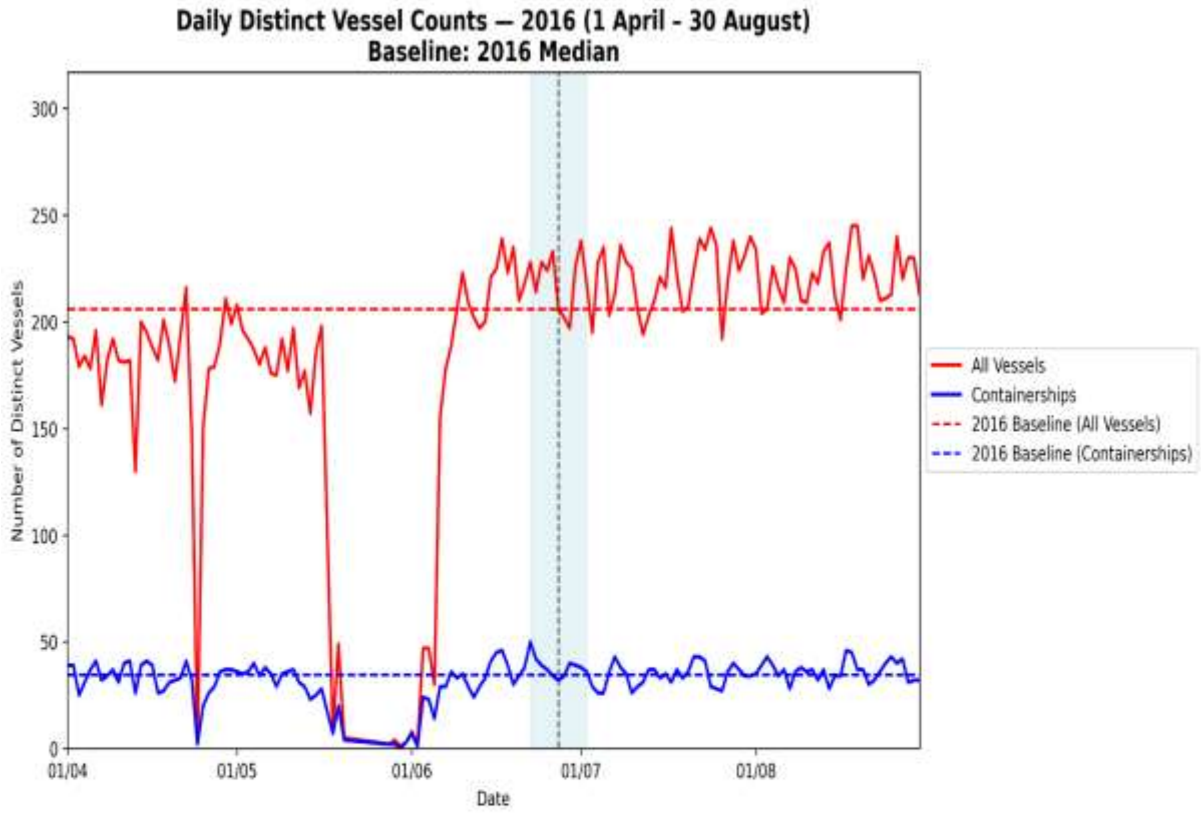


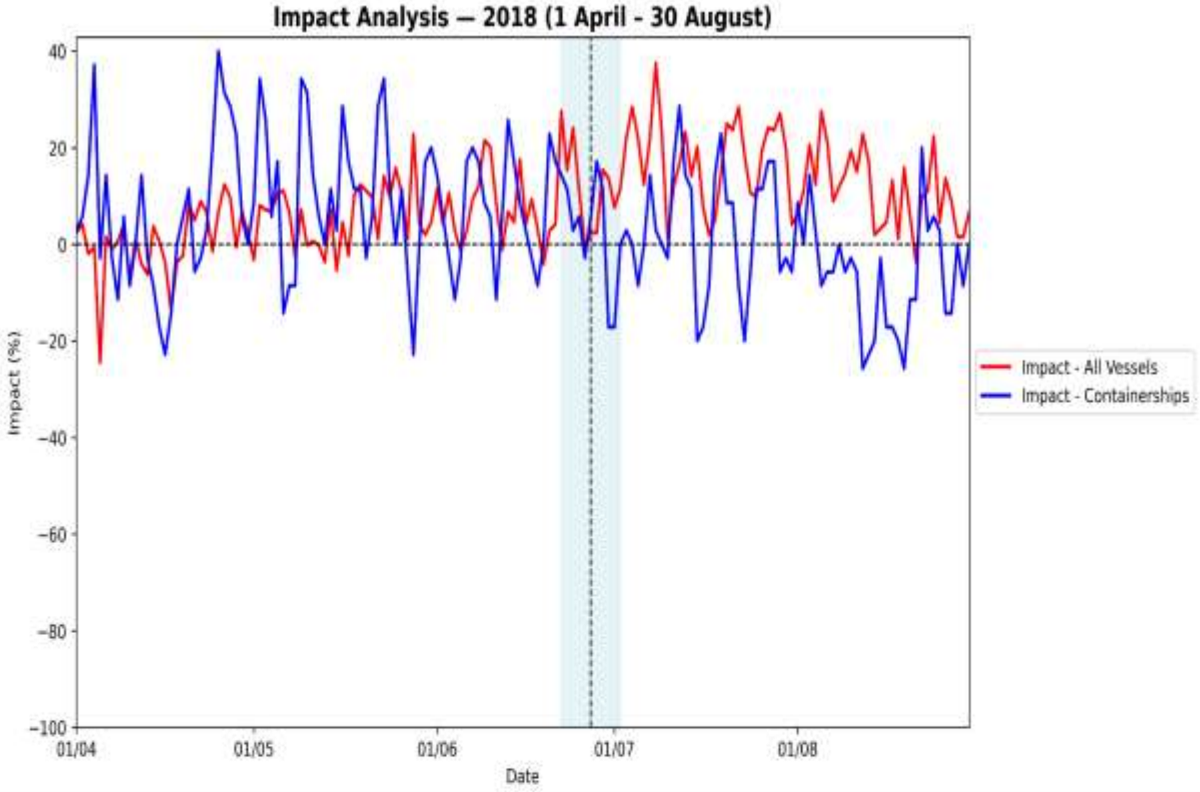

Daily Distinct Vessels — 2018
Number of Distinct Vessels
0
100
200
300
400
500
2018-04-01
2018-04-15
2018-04-29
2018-05-13
2018-05-27
2018-06-10
2018-06-24
2018-07-08
2018-07-22
2018-08-05
2018-08-19
All Vessels
Containerships


Impact Analysis — 2018
Impact (%)
60
40
20
0
−20
−40
−60
2018-04-01
2018-04-15
2018-04-29
2018-05-13
2018-05-27
2018-06-10
2018-06-24
2018-07-08
2018-07-22
2018-08-05
2018-08-19
Impact - All Vessels
Impact - Containerships

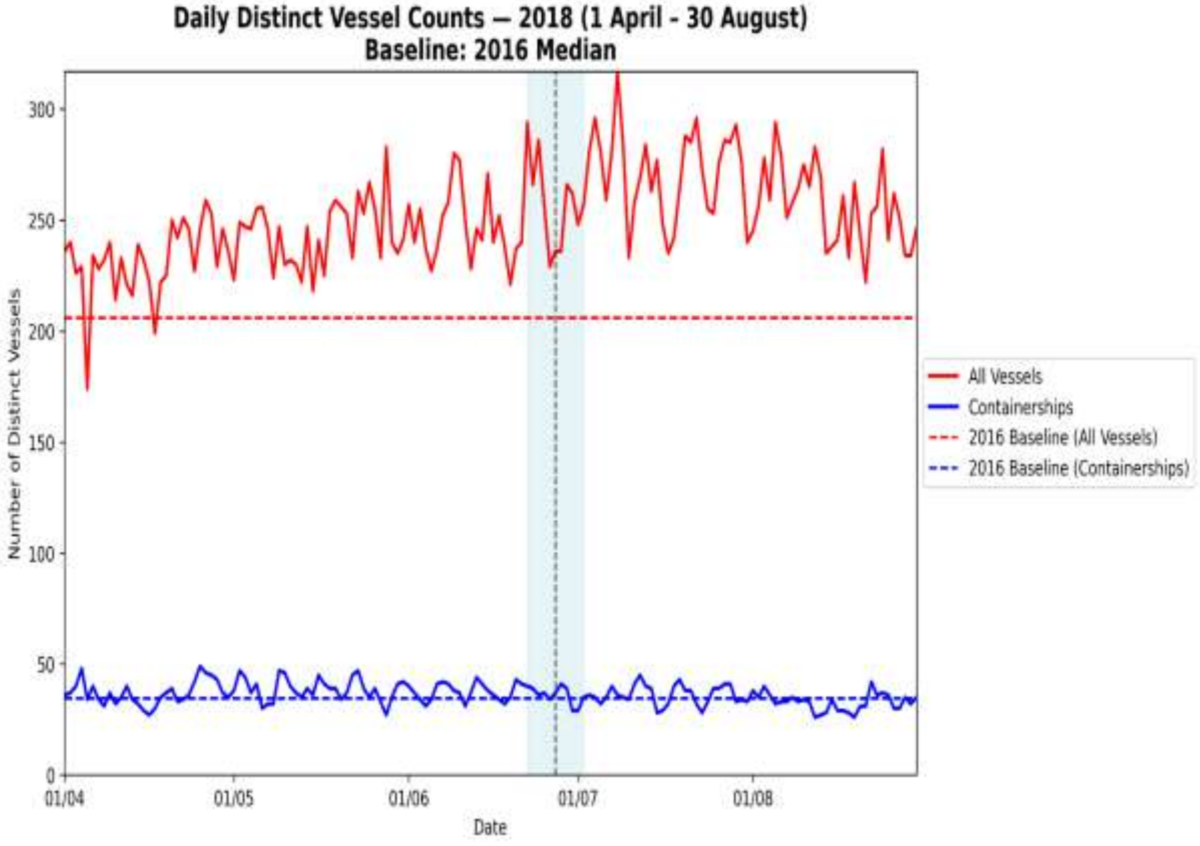
Los Angeles / Long Beach







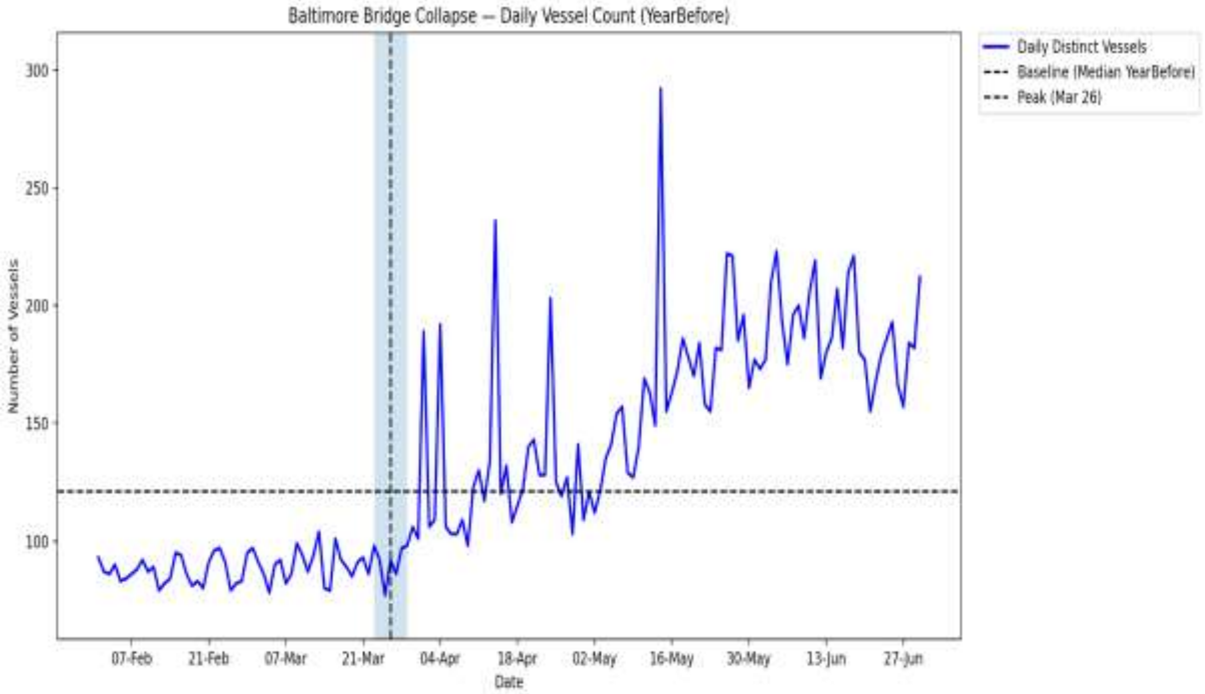
Impact Analysis — 2018 (1 April - 30 August)

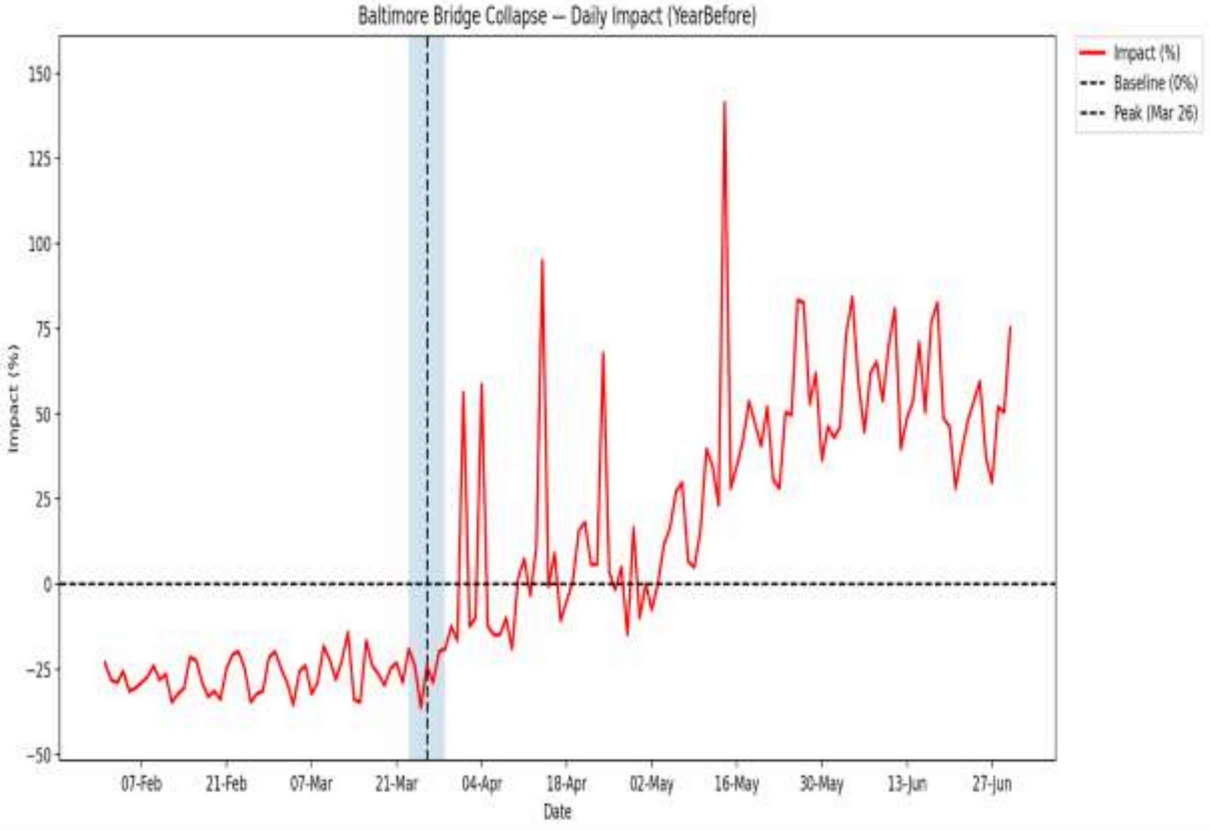


Daily Distinct Vessel Counts — 2018 (1 April - 30 August)
Baseline: 2016 Median

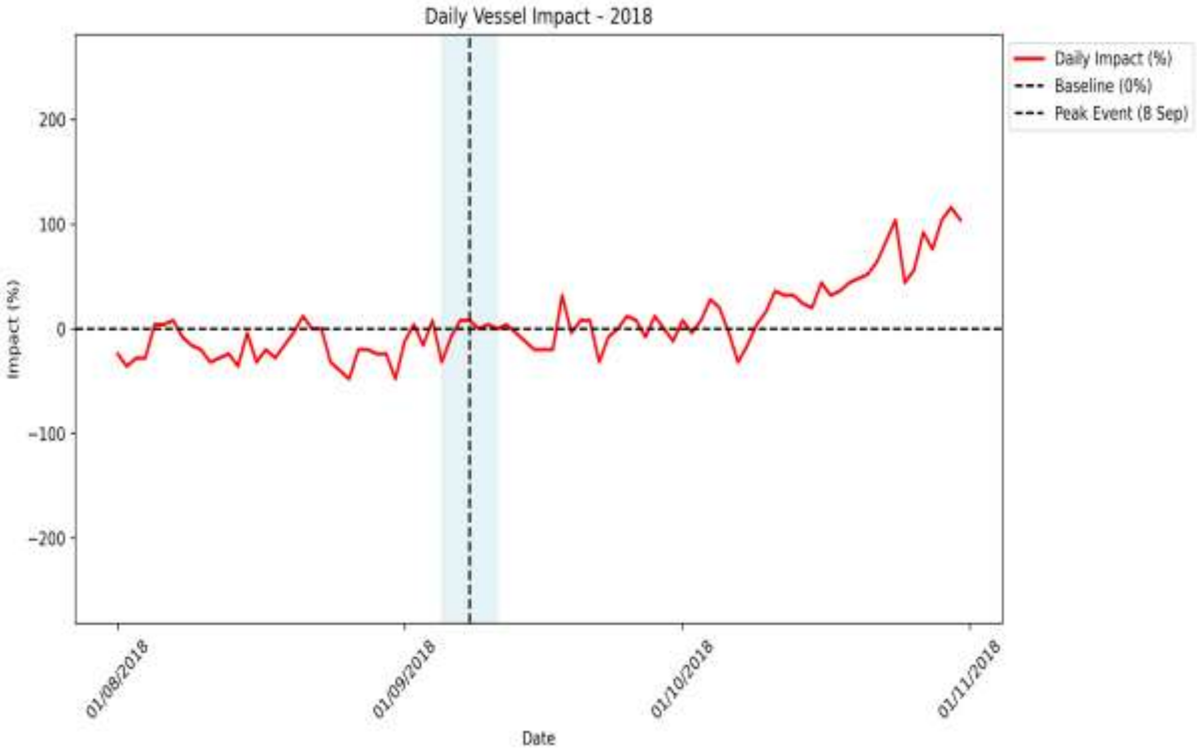
4.5 Maritime Accidents USA

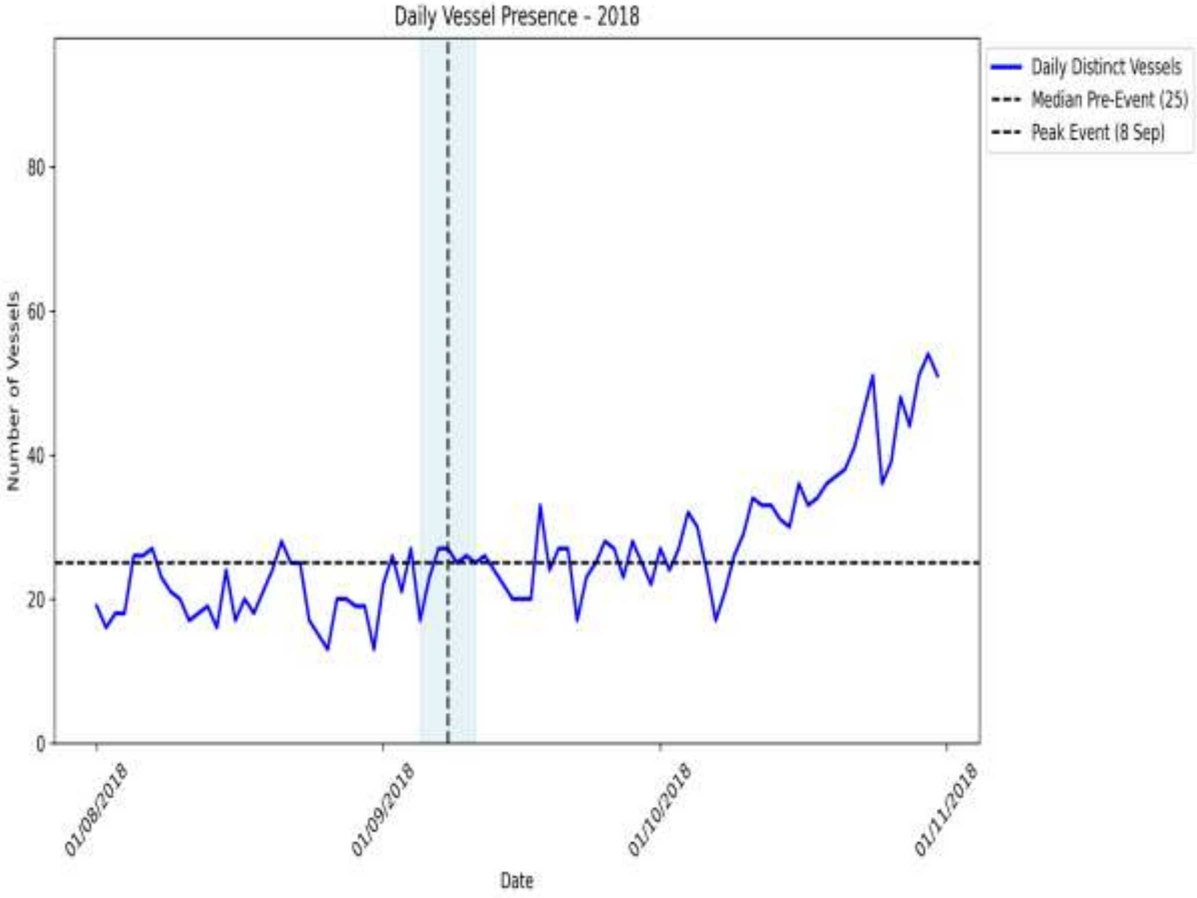
4.5.1 Collision on Baltimore Bridge and Collapse Case

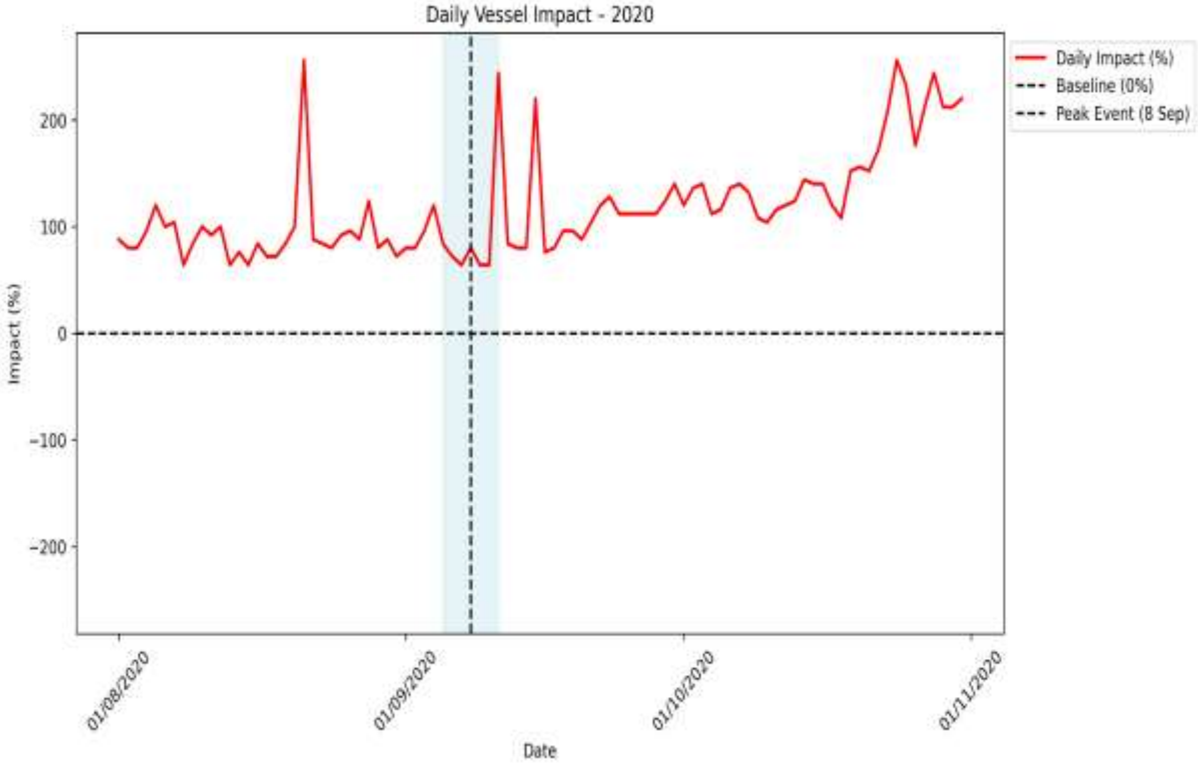


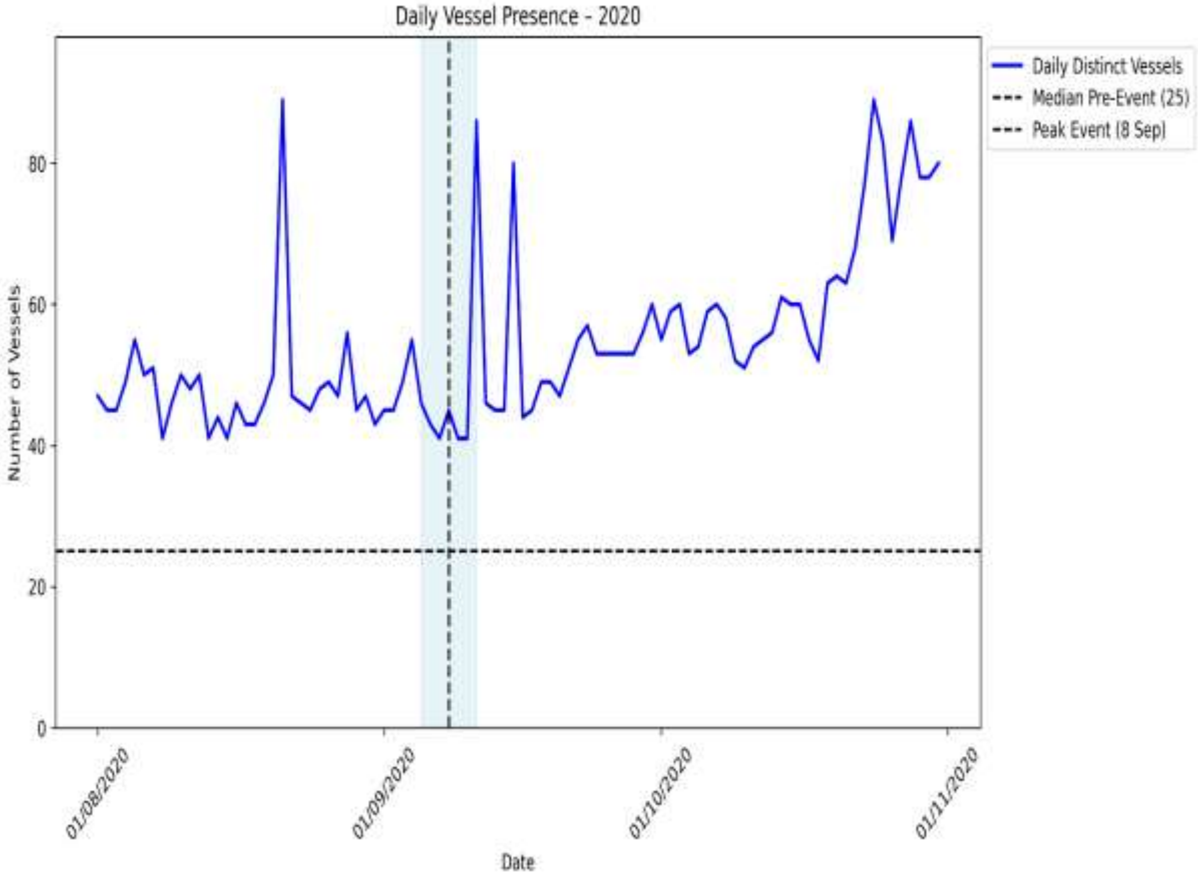


4.5.2 Capsizing of Golden Ray Case

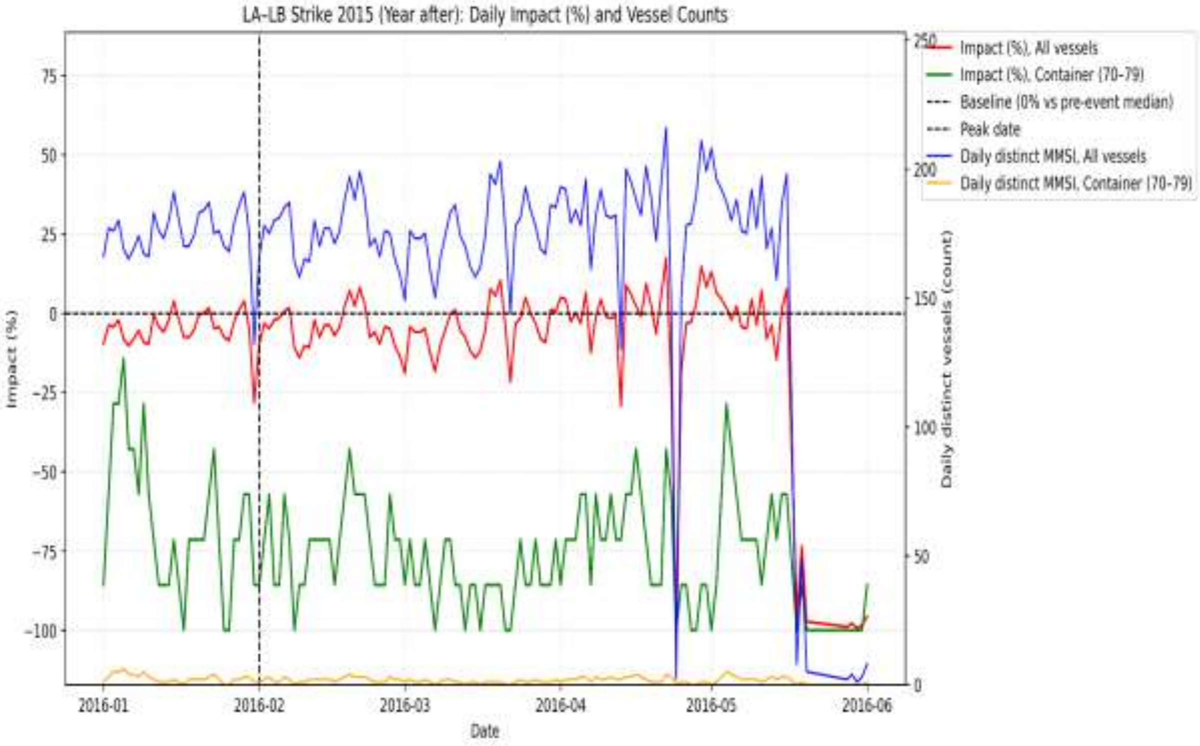





Daily Vessel Impact - 2020
Impact (%)
200
100
0
−100
−200
01/08/2020
01/09/2020
01/10/2020
01/11/2020
Date
Daily Impact (%)
Baseline (0%)
Peak Event (8 Sep)

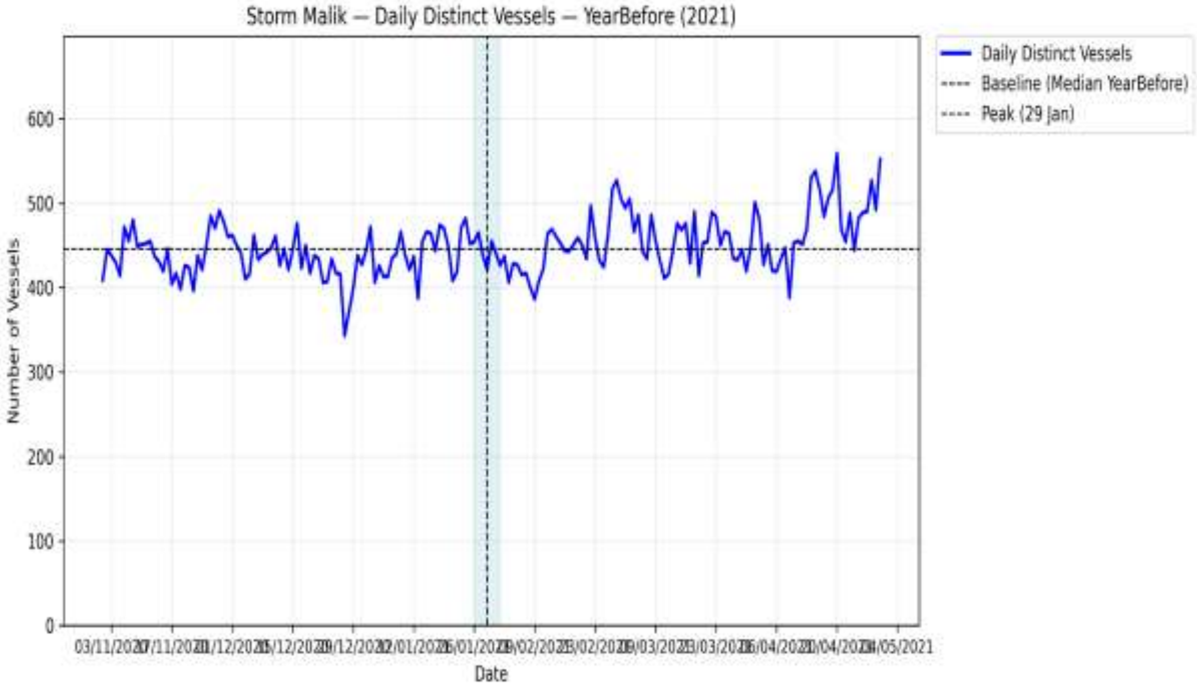

Daily Vessel Presence - 2020
Number of Vessels
80
60
40
20
0
01/08/2020
01/09/2020
01/10/2020
01/11/2020
Date
Daily Distinct Vessels
Median Pre-Event (25)
Peak Event (8 Sep)

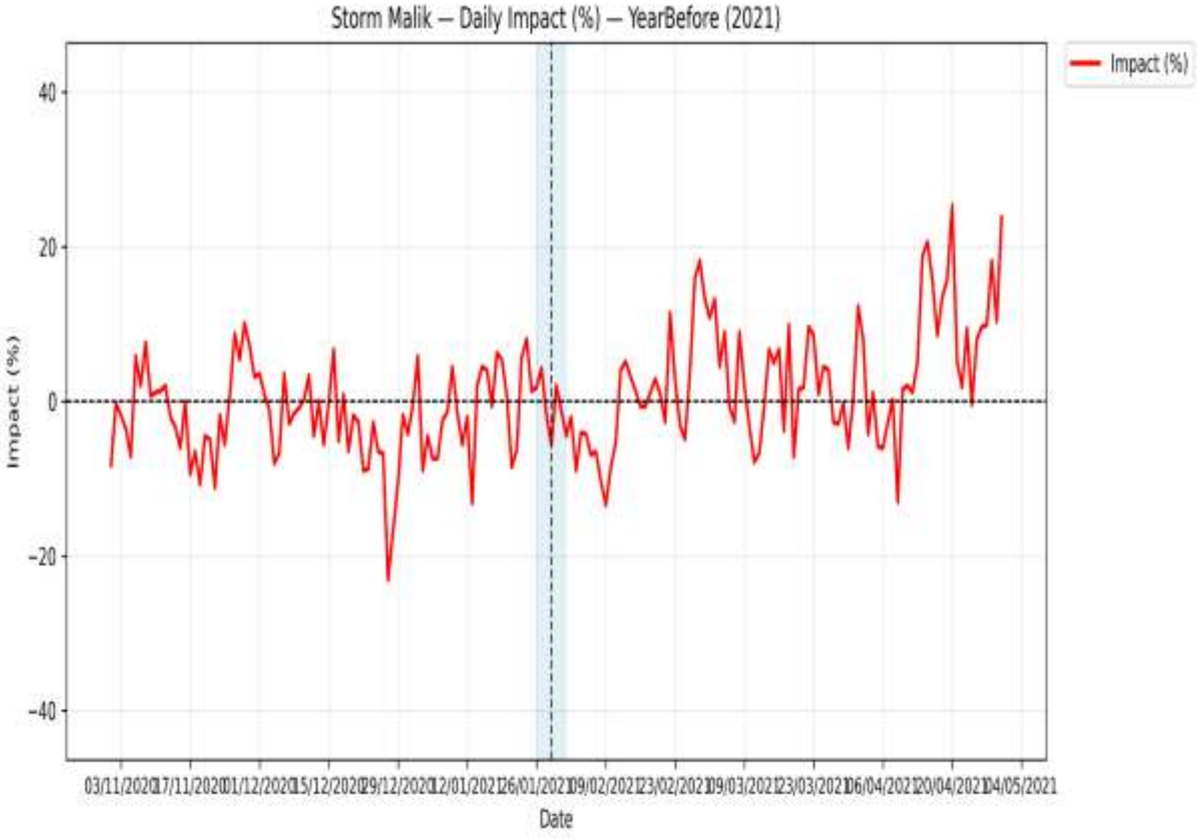
4.6 ILWU PMA Labour Dispute 2014-15

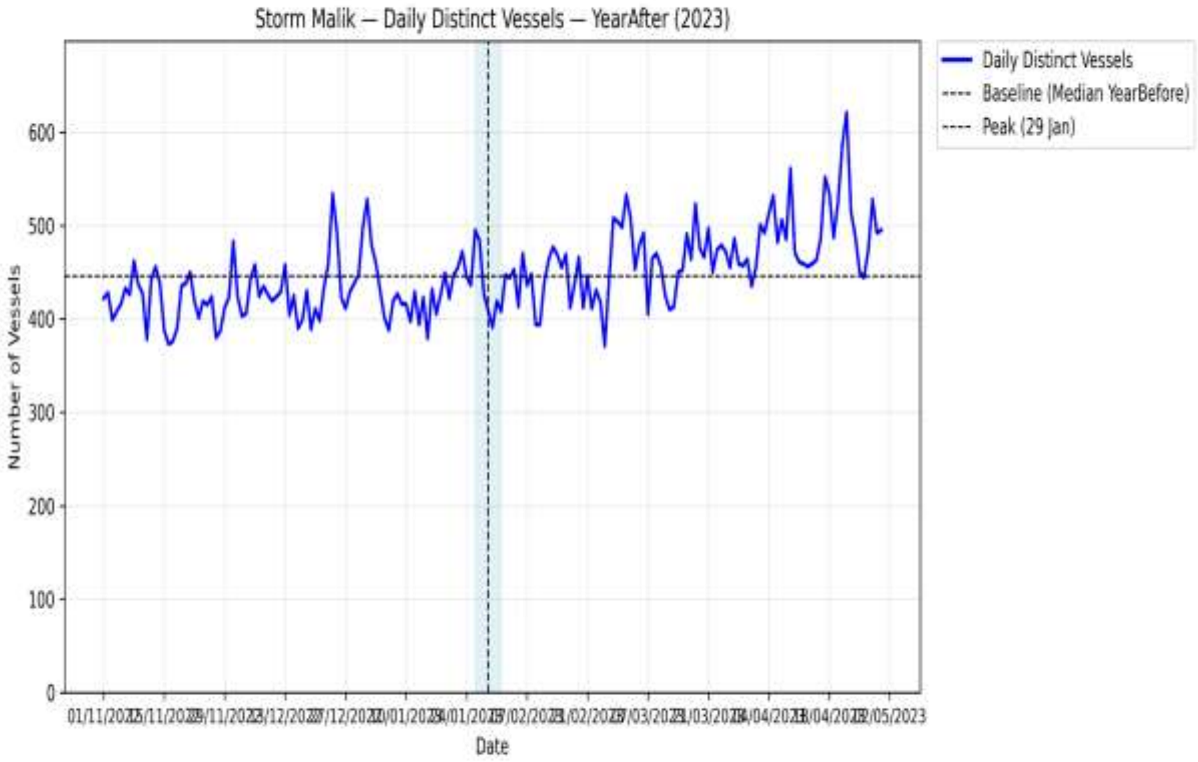


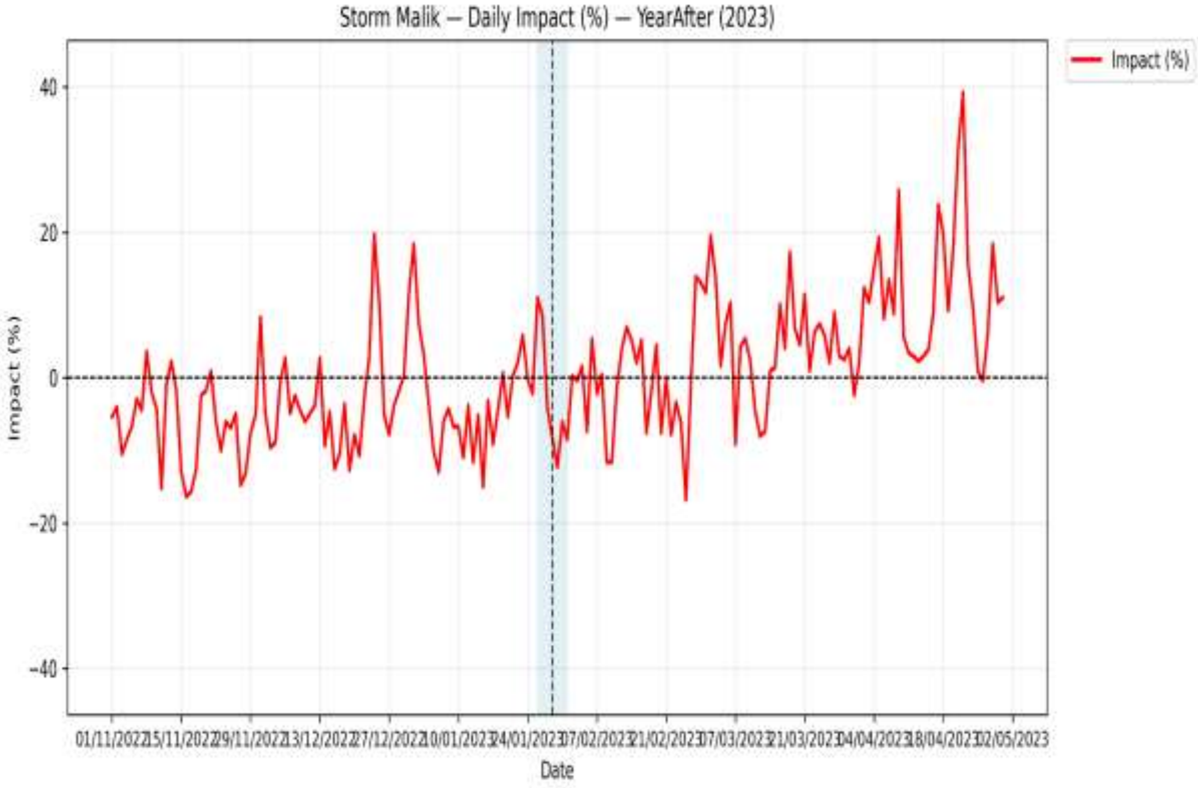
Appendix B - Additional Diagrams (Denmark Cases)

4.7 Natural Disruption Denmark

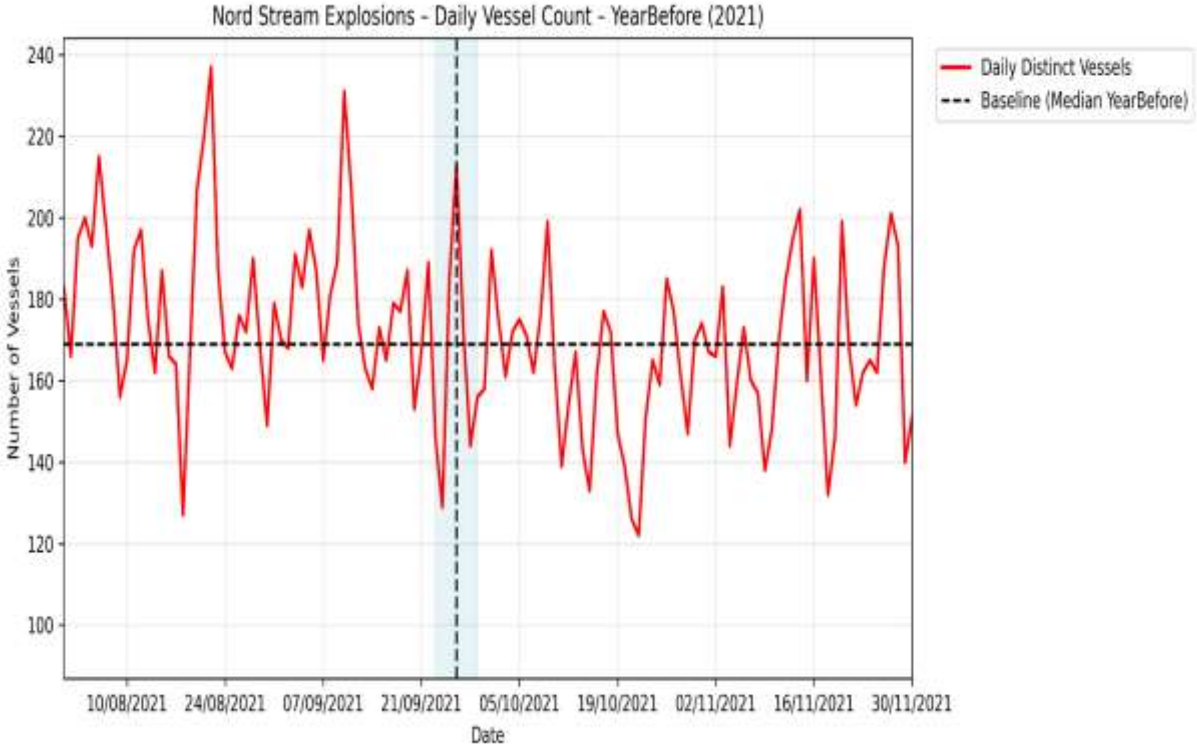


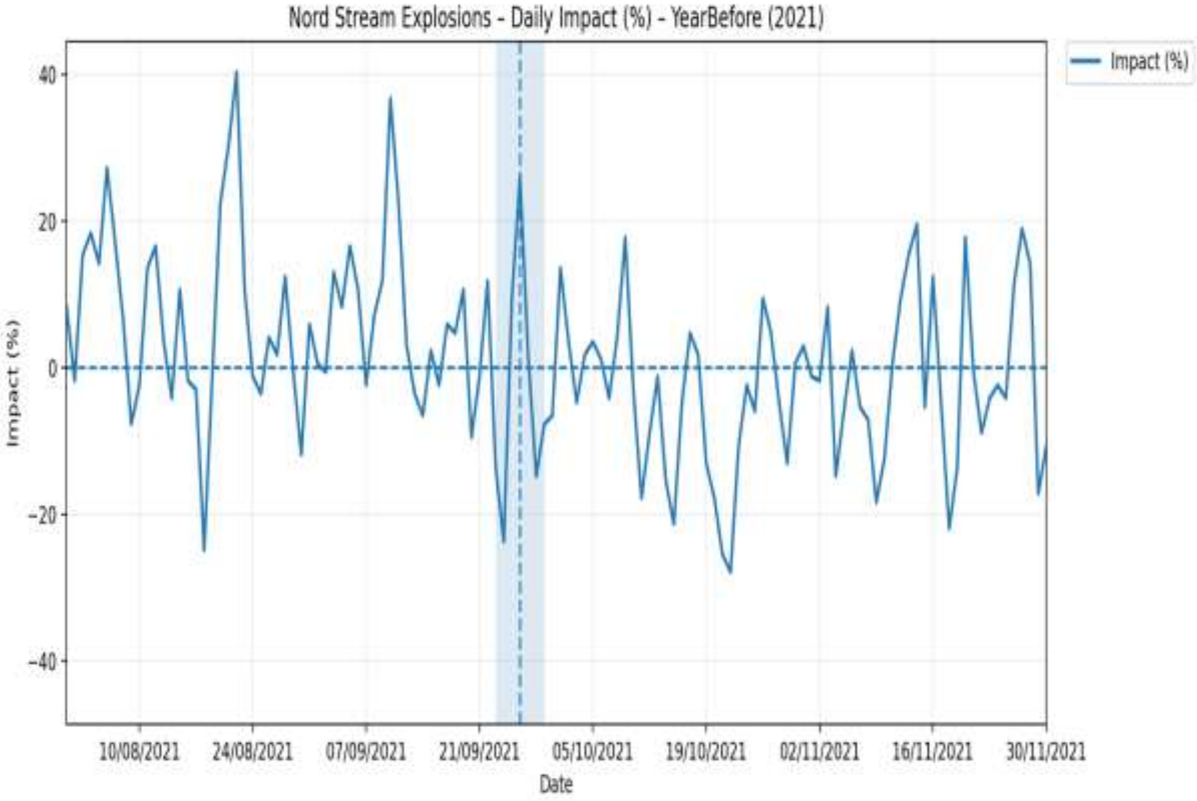


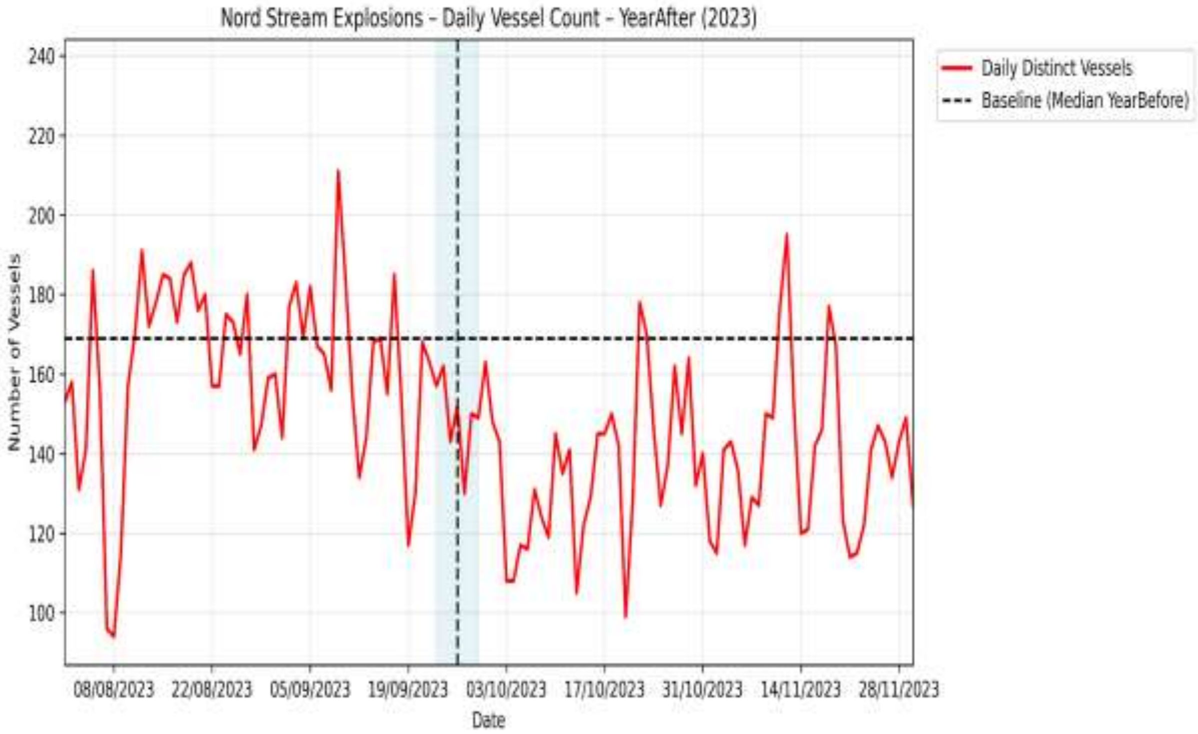

Storm Malik — Daily Distinct Vessels — YearAfter (2023)
Daily Distinct Vessels
Baseline (Median YearBefore)
Peak (29 Jan)
Number of Vessels
0
100
200
300
400
500
600
01/11/2022
15/11/2022
29/11/2022
13/12/2022
27/12/2022
10/01/2023
24/01/2023
07/02/2023
21/02/2023
07/03/2023
21/03/2023
04/04/2023
18/04/2023
02/05/2023
Date

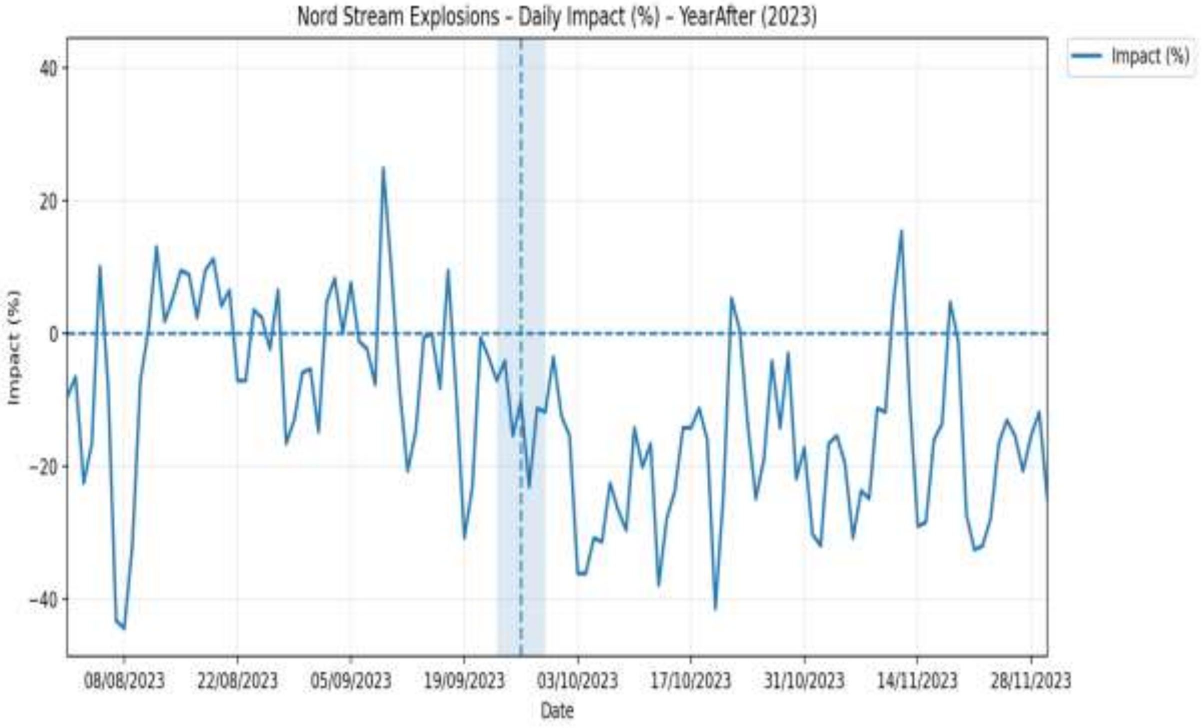

Storm Malik — Daily Impact (%) — YearAfter (2023)
Impact (%)
Impact (%)
−40
−20
0
20
40
01/11/2022
15/11/2022
29/11/2022
13/12/2022
27/12/2022
10/01/2023
24/01/2023
07/02/2023
21/02/2023
07/03/2023
21/03/2023
04/04/2023
18/04/2023
02/05/2023
Date

4.8 Geopolitical Shock Denmark



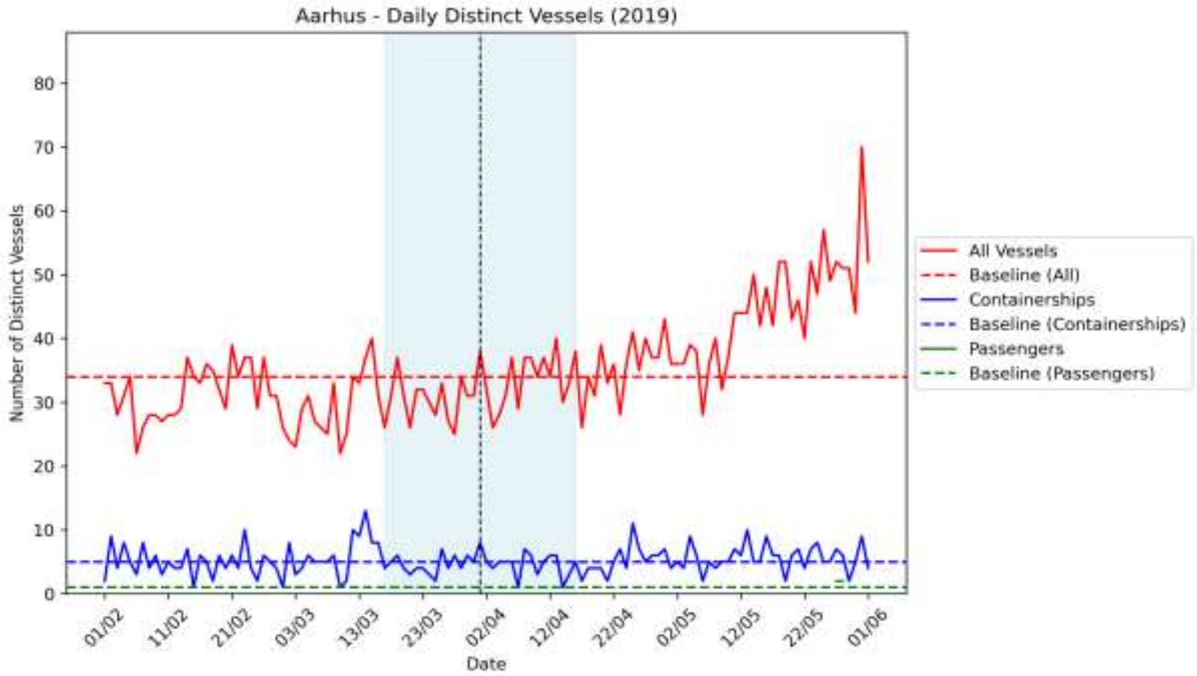


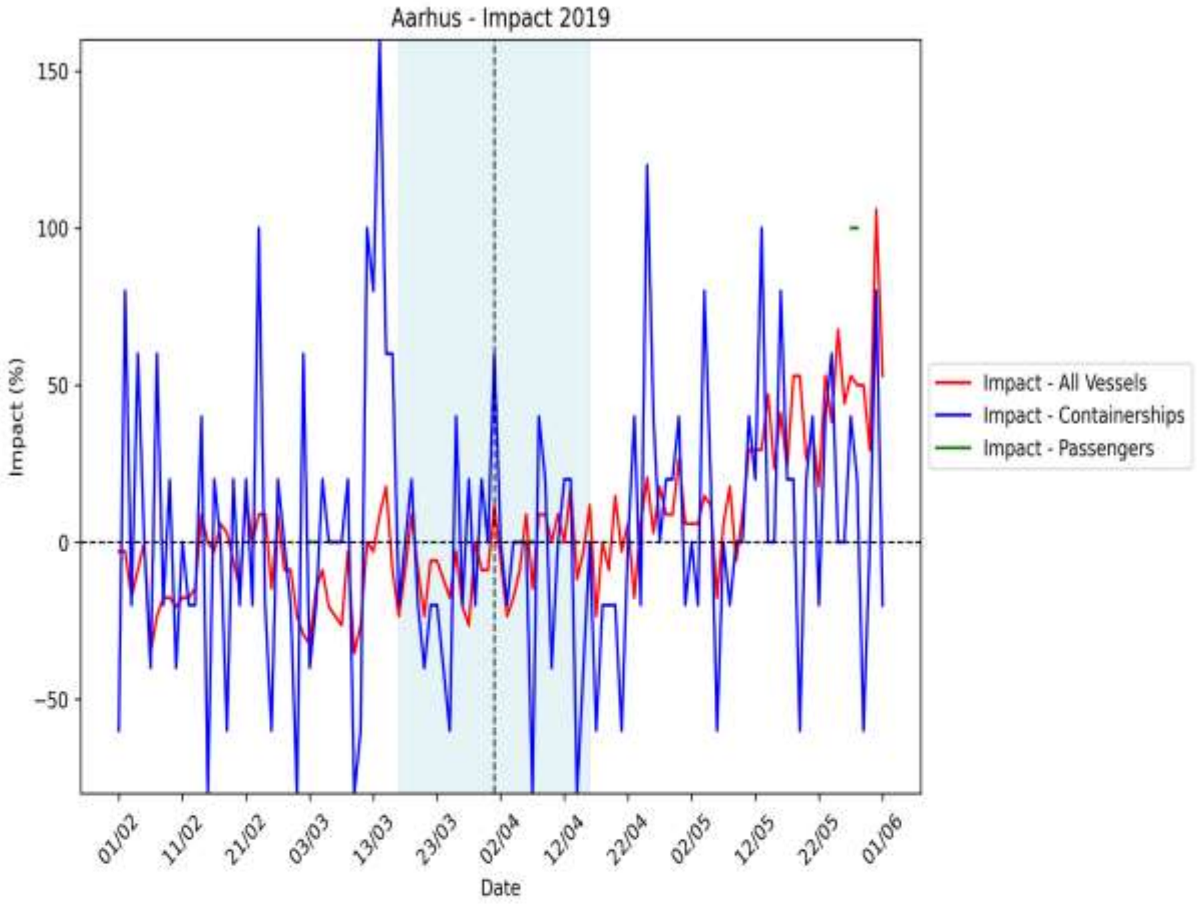

Nord Stream Explosions - Daily Vessel Count - YearAfter (2023)
Daily Distinct Vessels
Baseline (Median YearBefore)
Number of Vessels
240
220
200
180
160
140
120
100
08/08/2023
22/08/2023
05/09/2023
19/09/2023
03/10/2023
17/10/2023
31/10/2023
14/11/2023
28/11/2023
Date

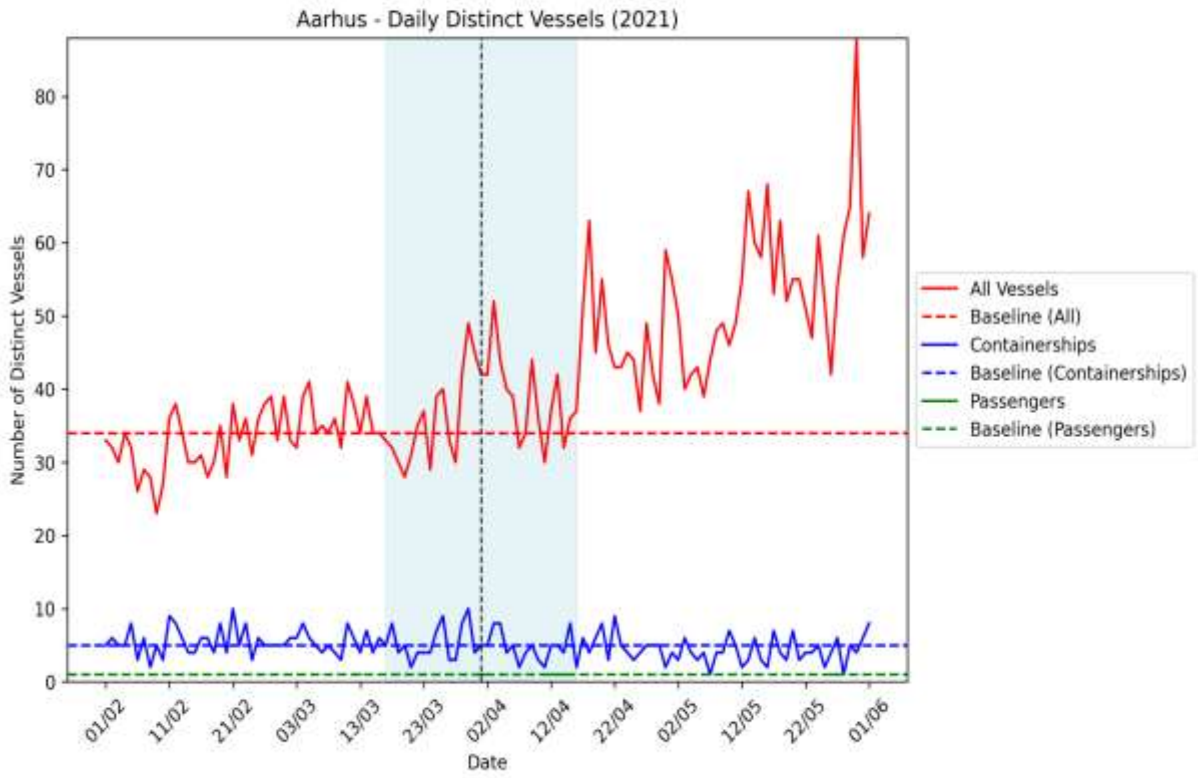

Nord Stream Explosions - Daily Impact (%) - YearAfter (2023)
Impact (%)
Impact (%)
40
20
0
-20
-40
08/08/2023
22/08/2023
05/09/2023
19/09/2023
03/10/2023
17/10/2023
31/10/2023
14/11/2023
28/11/2023
Date

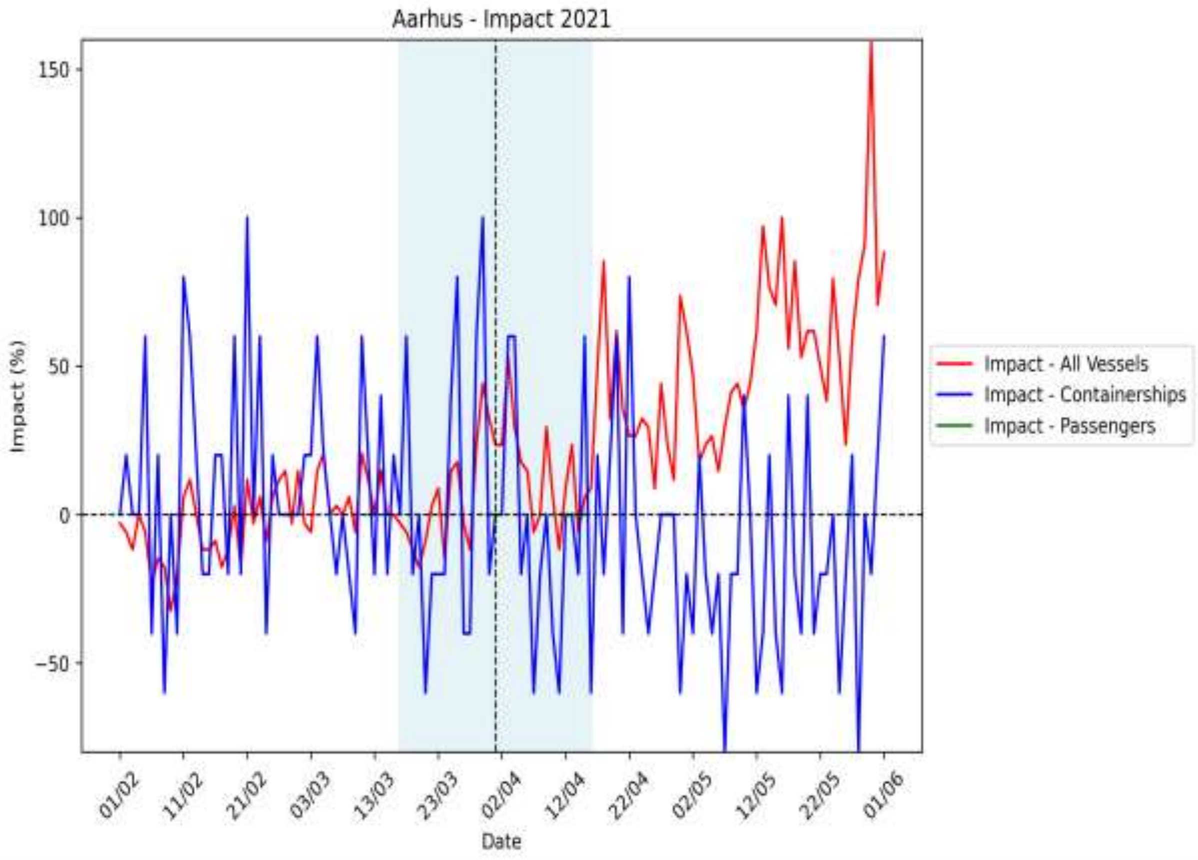
4.9 Covid -19 First Wave Denmark

Aarhus

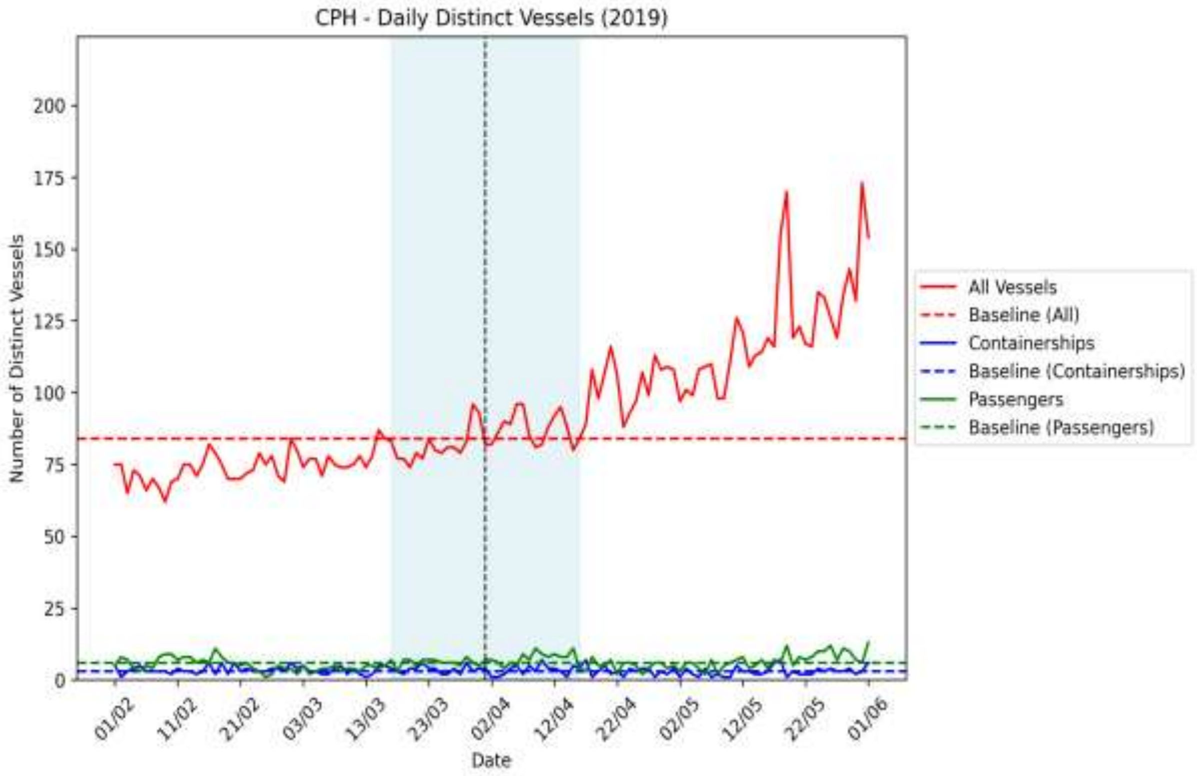


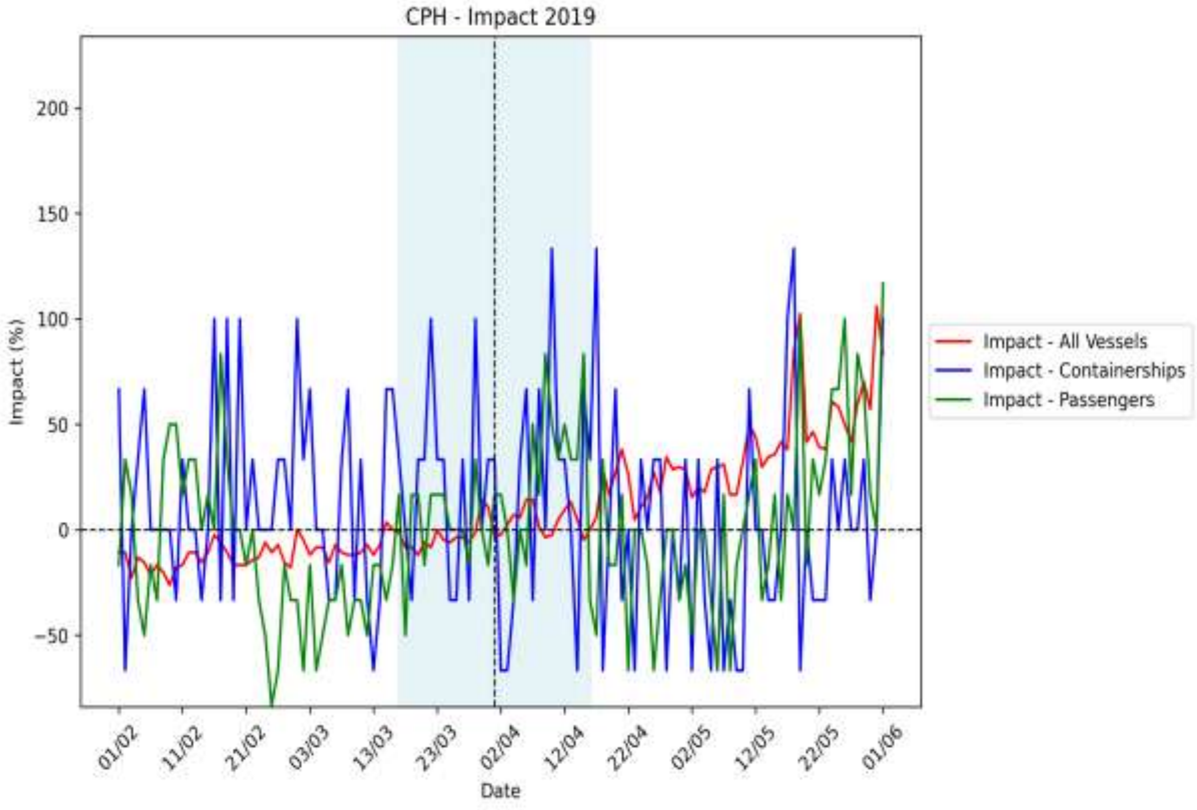


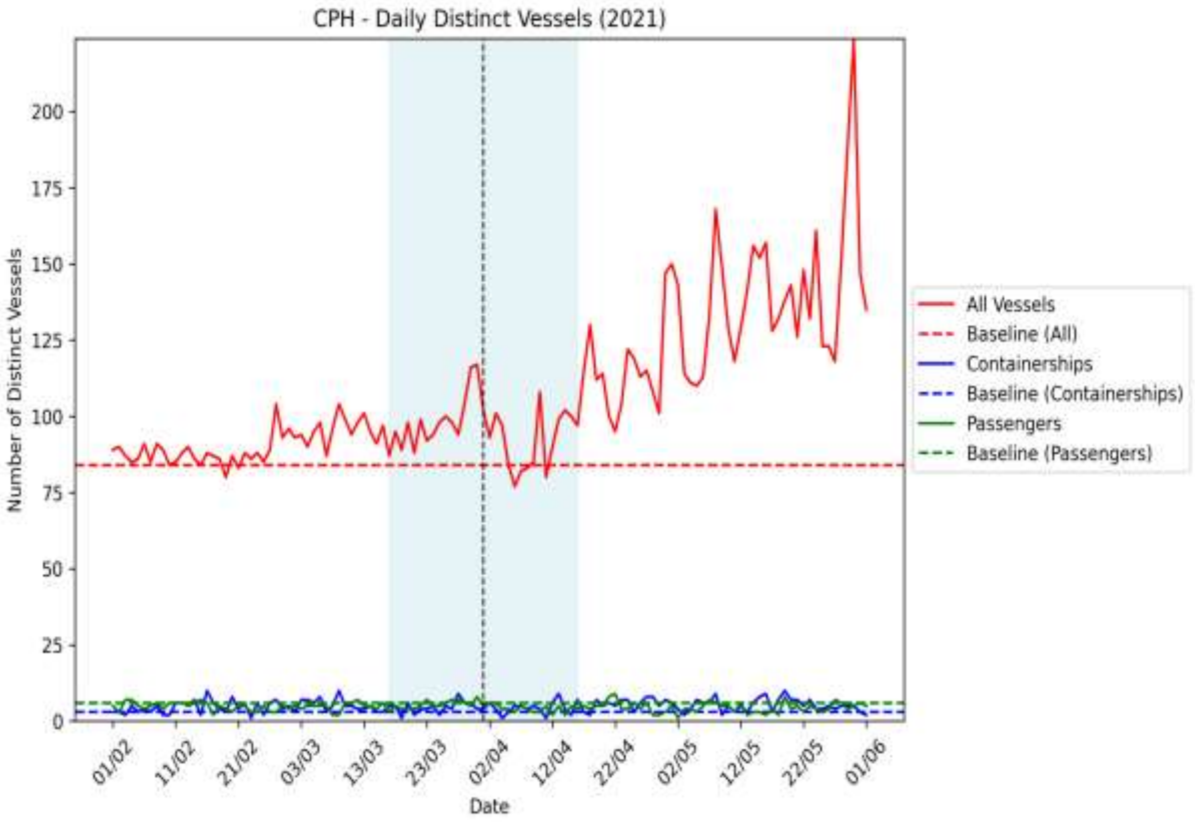

Aarhus - Daily Distinct Vessels (2021)
Number of Distinct Vessels
0
10
20
30
40
50
60
70
80
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
Date
All Vessels
Baseline (All)
Containerships
Baseline (Containerships)
Passengers
Baseline (Passengers)

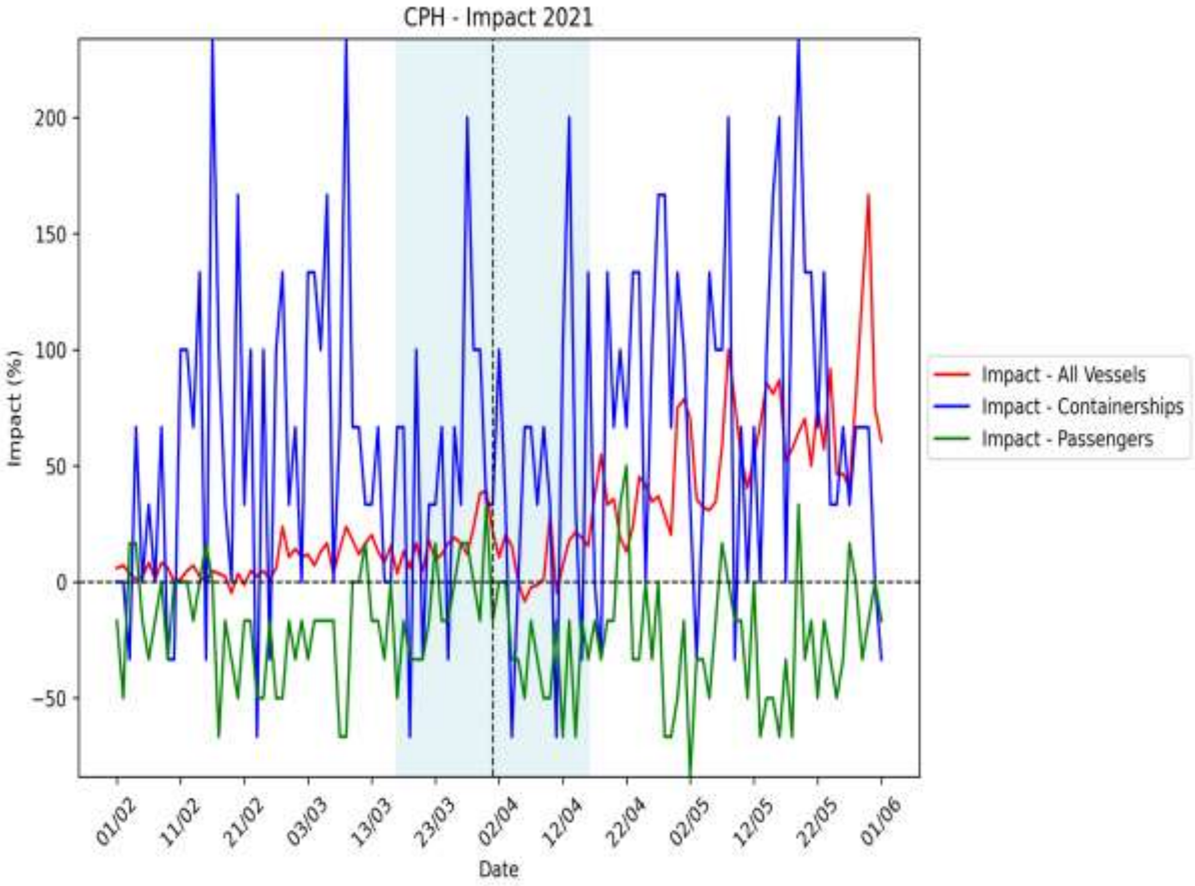

Aarhus - Impact 2021
Impact (%)
150
100
50
0
−50
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
Date
Impact - All Vessels
Impact - Containerships
Impact - Passengers

Copenhagen

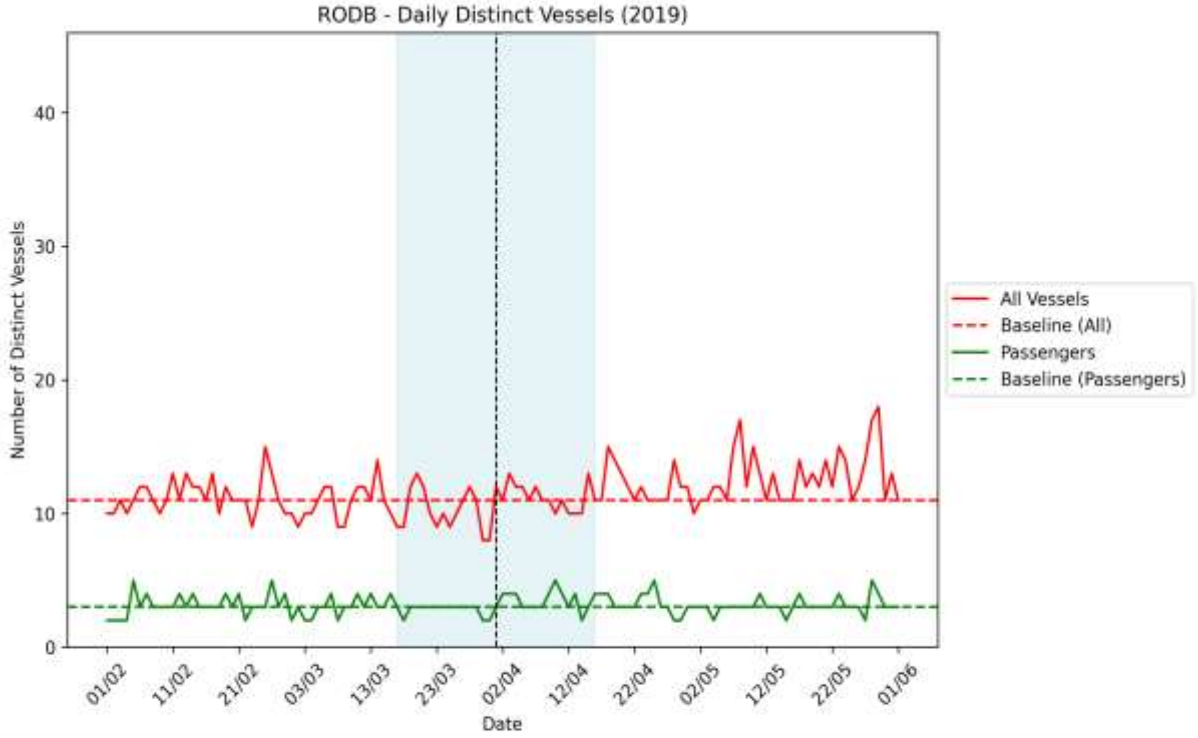

CPH - Daily Distinct Vessels (2019)
Number of Distinct Vessels
0
25
50
75
100
125
150
175
200
Date
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
All Vessels
Baseline (All)
Containerships
Baseline (Containerships)
Passengers
Baseline (Passengers)

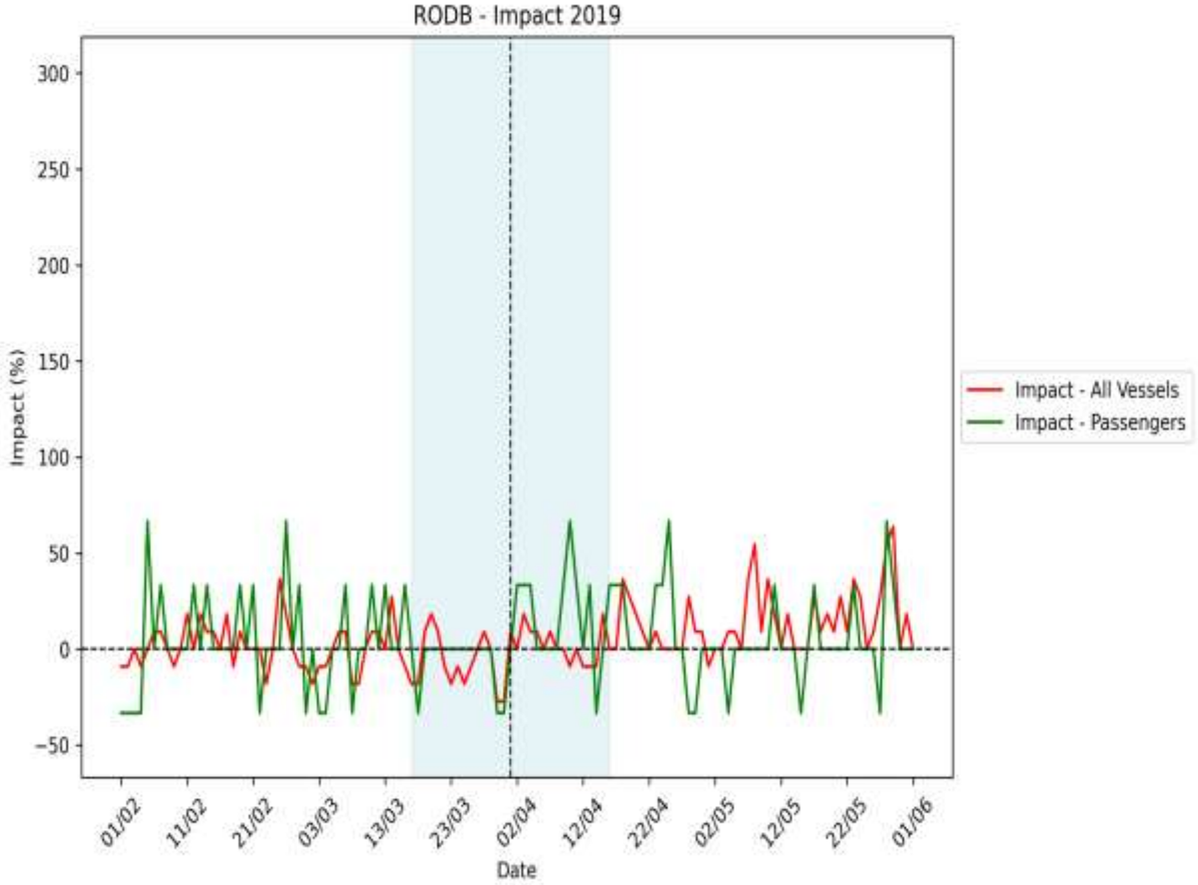

CPH - Impact 2019
Impact (%)
−50
0
50
100
150
200
Date
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
Impact - All Vessels
Impact - Containerships
Impact - Passengers

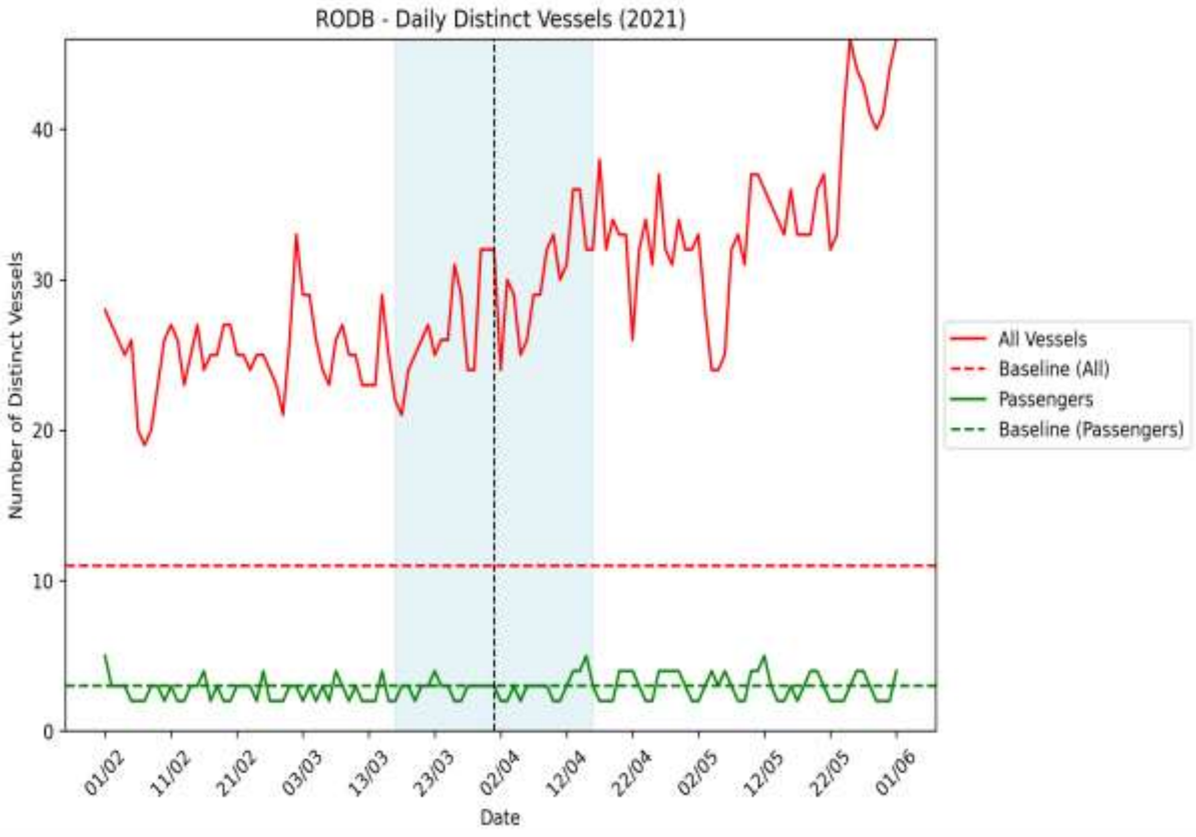

CPH - Daily Distinct Vessels (2021)
Number of Distinct Vessels
0
25
50
75
100
125
150
175
200
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
Date
All Vessels
Baseline (All)
Containerships
Baseline (Containerships)
Passengers
Baseline (Passengers)

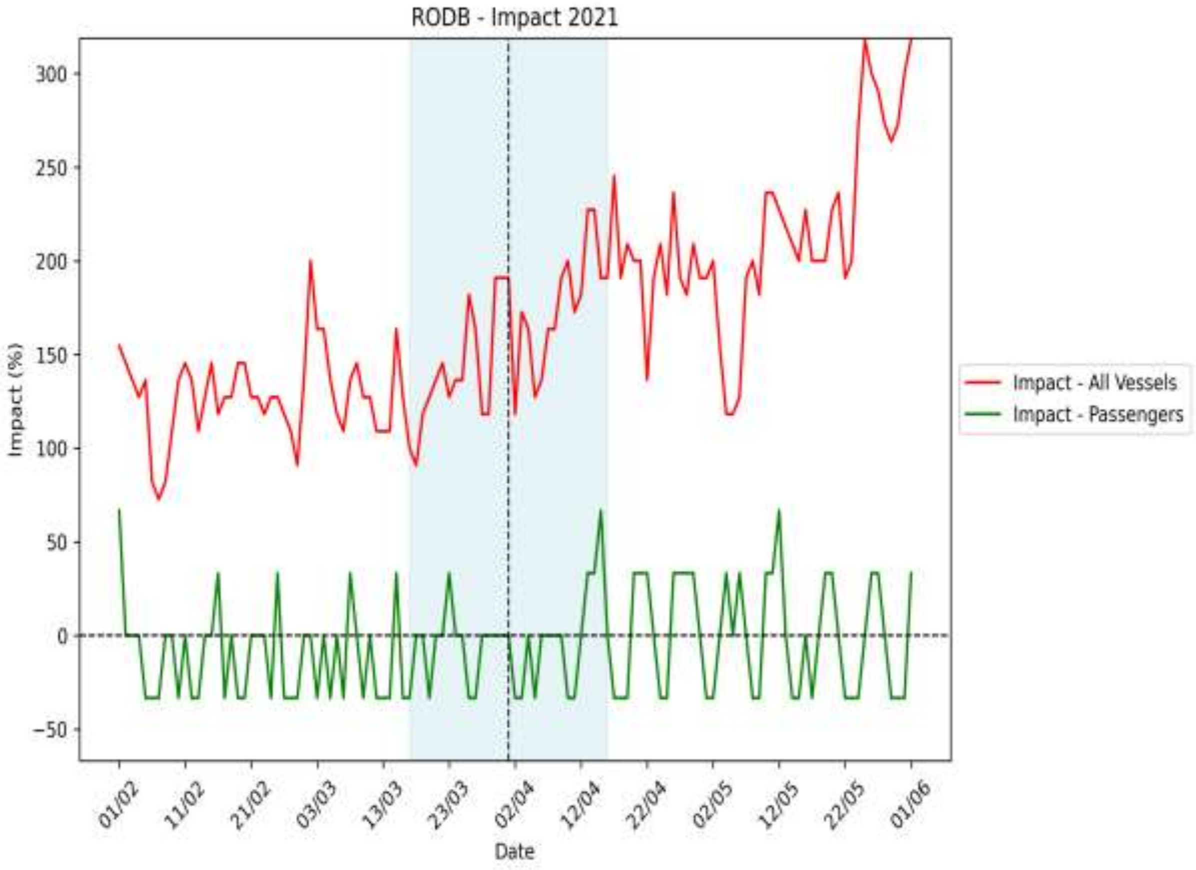

CPH - Impact 2021
Impact (%)
−50
0
50
100
150
200
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
Date
Impact - All Vessels
Impact - Containerships
Impact - Passengers

Robhavn


RODB - Daily Distinct Vessels (2019)
Number of Distinct Vessels
0
10
20
30
40
Date
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
All Vessels
Baseline (All)
Passengers
Baseline (Passengers)

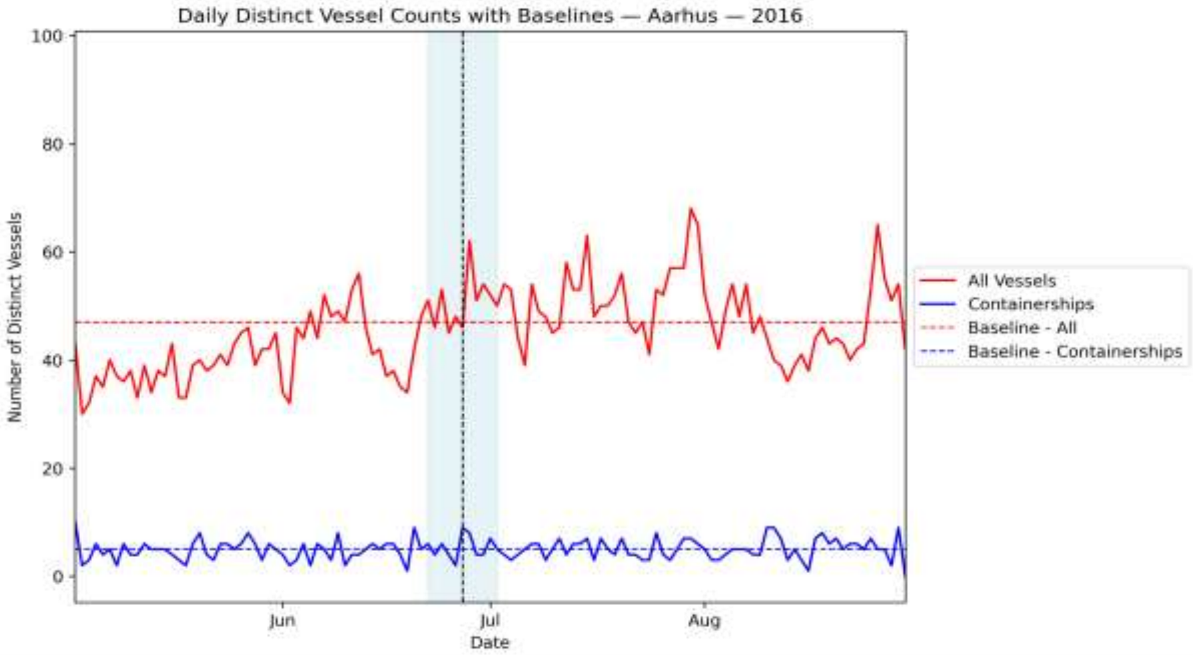

RODB - Impact 2019
Impact (%)
−50
0
50
100
150
200
250
300
Date
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
Impact - All Vessels
Impact - Passengers

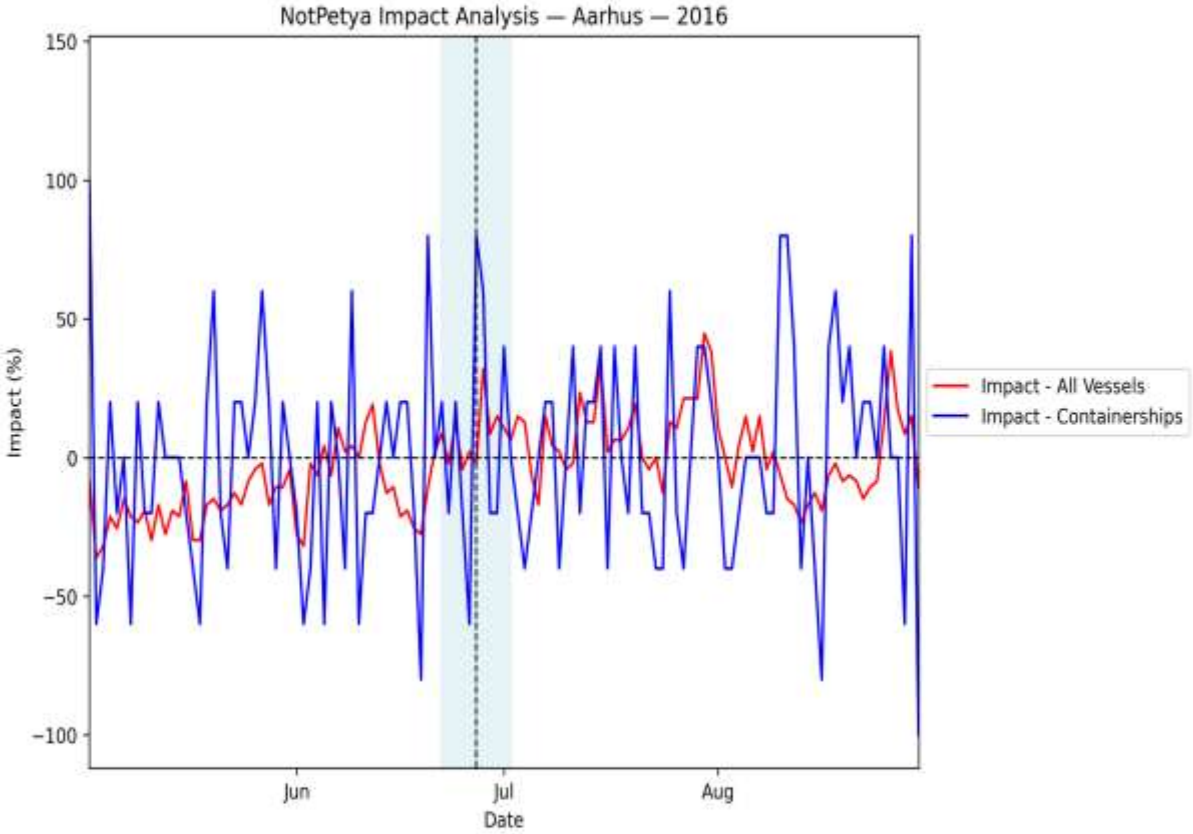

RODB - Daily Distinct Vessels (2021)
Number of Distinct Vessels
0
10
20
30
40
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
Date
All Vessels
Baseline (All)
Passengers
Baseline (Passengers)

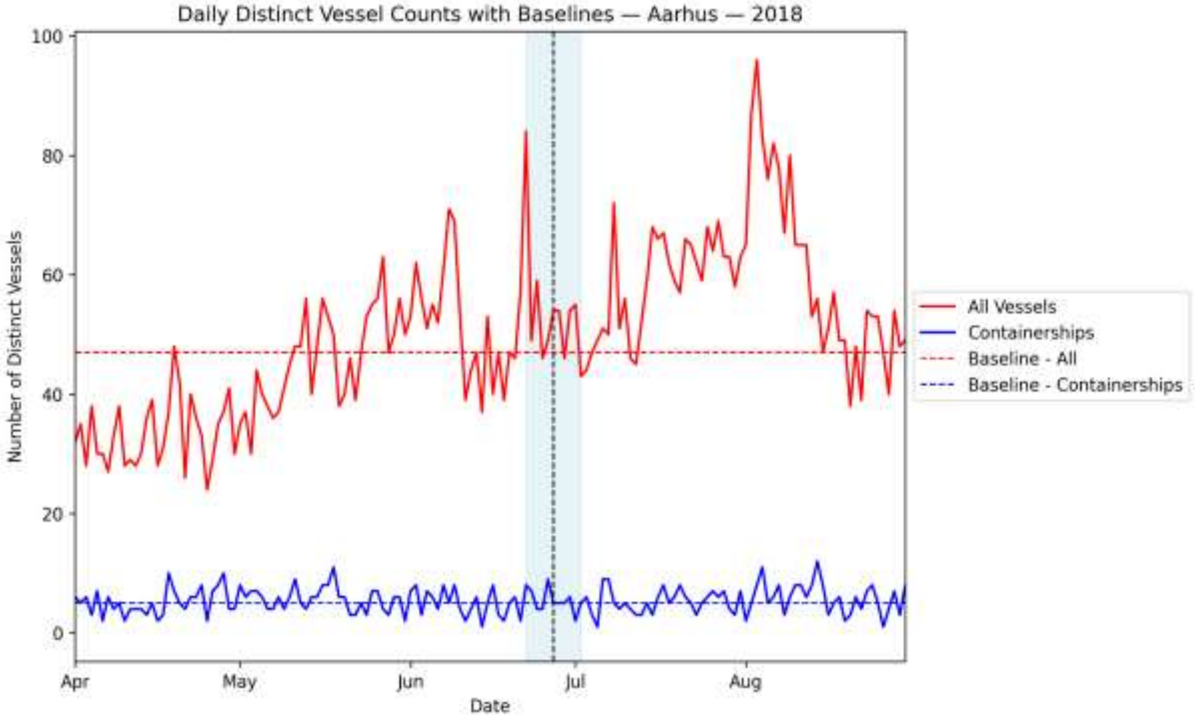

RODB - Impact 2021
Impact (%)
−50
0
50
100
150
200
250
300
01/02
11/02
21/02
03/03
13/03
23/03
02/04
12/04
22/04
02/05
12/05
22/05
01/06
Date
Impact - All Vessels
Impact - Passengers

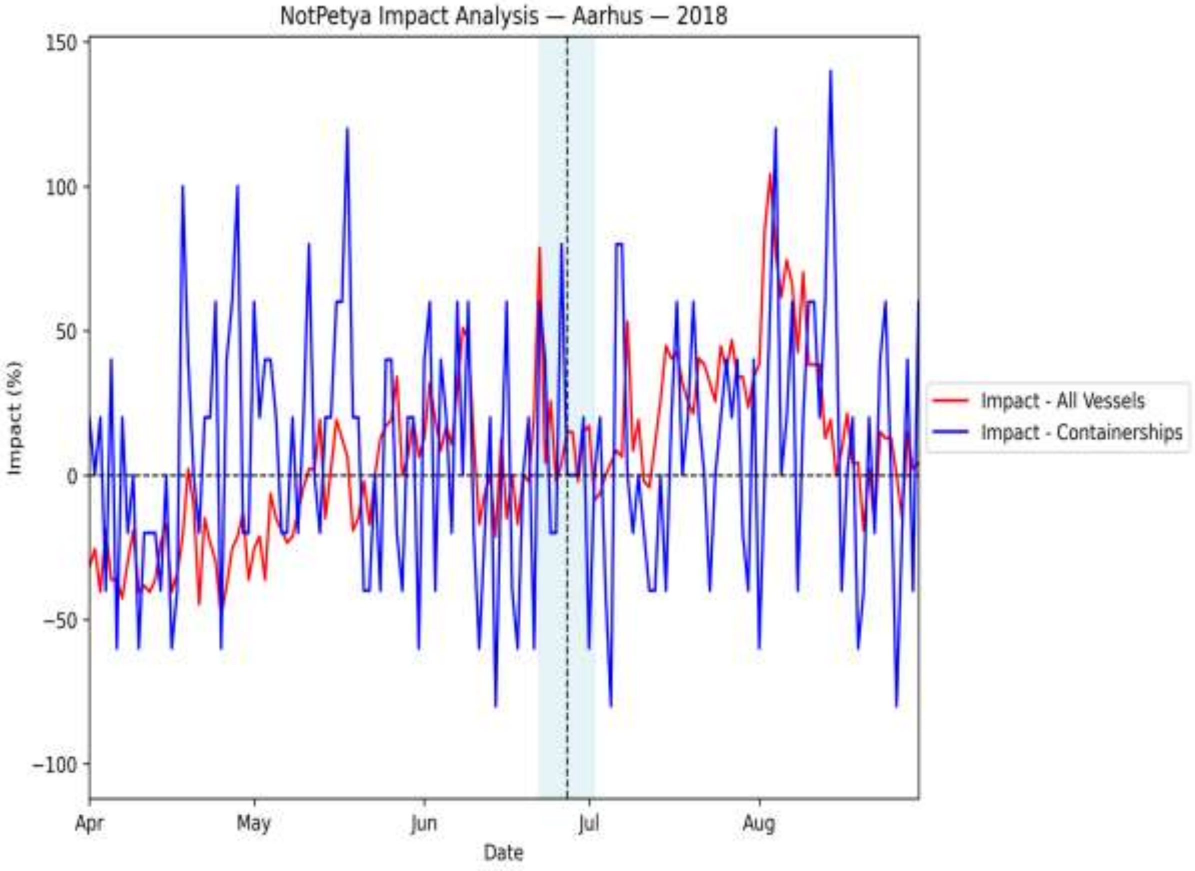
4.10 NotPetya Cyberattack Denmark Terminals

Aarhus



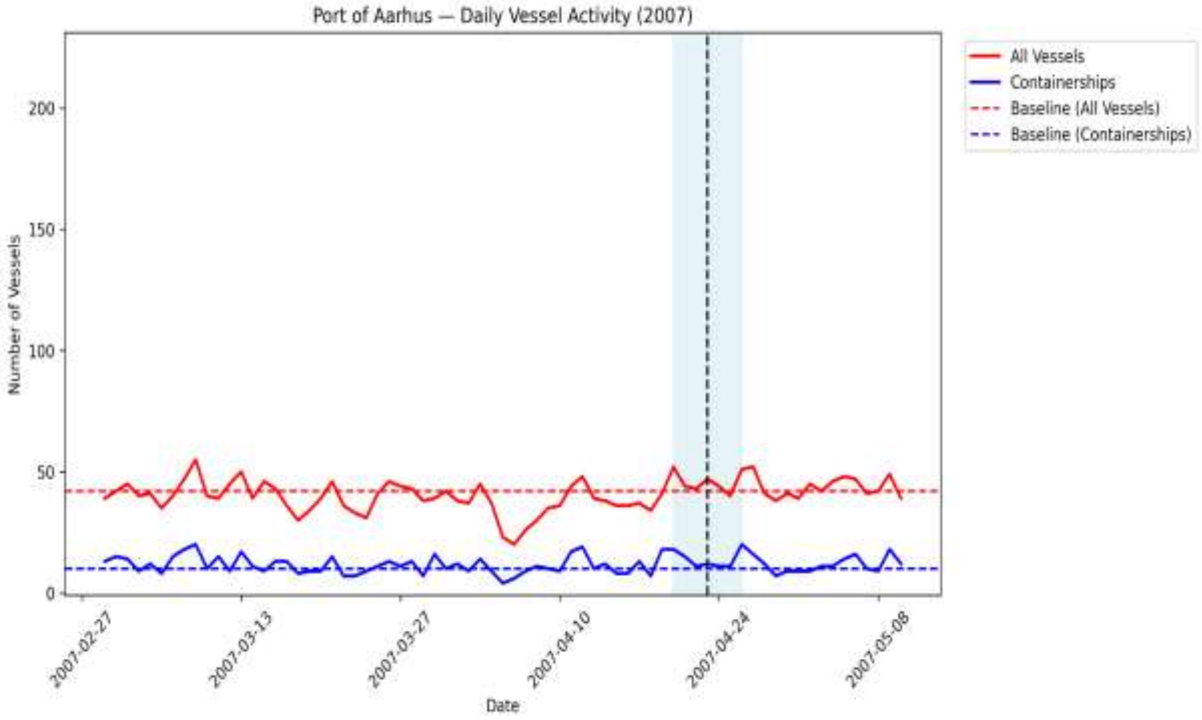


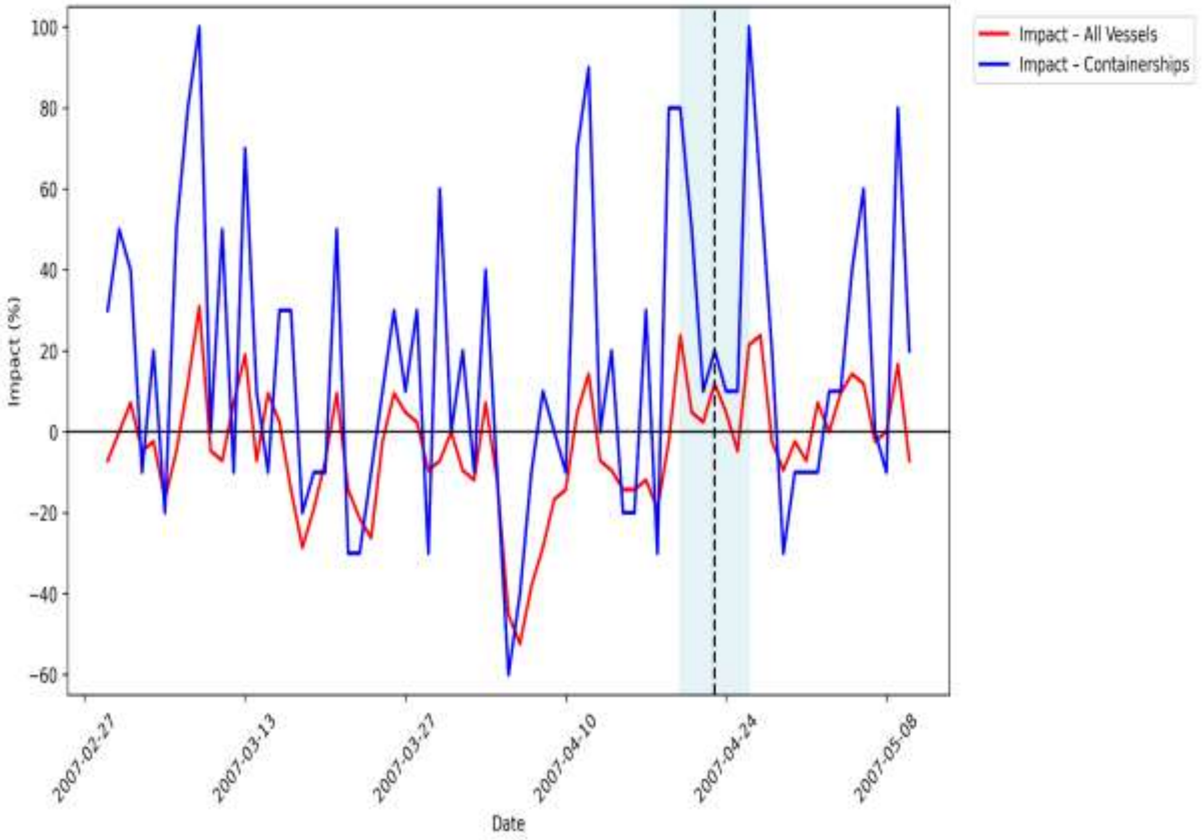

Daily Distinct Vessel Counts with Baselines — Aarhus — 2018
Number of Distinct Vessels
100
80
60
40
20
0
Apr
May
Jun
Jul
Aug
Date
All Vessels
Containerships
Baseline - All
Baseline - Containerships

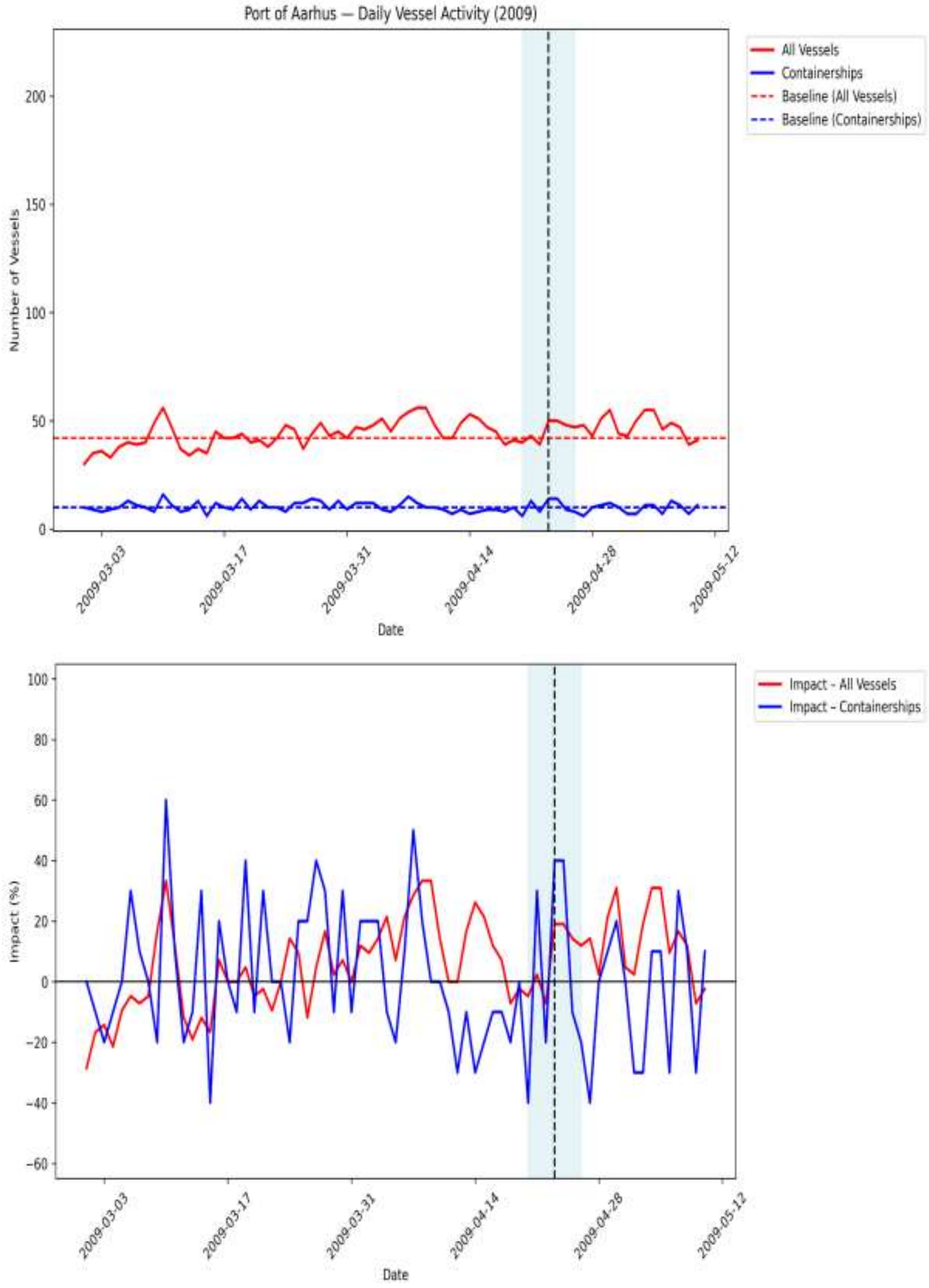

NotPetya Impact Analysis — Aarhus — 2018
Impact (%)
150
100
50
0
−50
−100
Apr
May
Jun
Jul
Aug
Date
Impact - All Vessels
Impact - Containerships

4.11 Labour Dispute Strikes Denmark

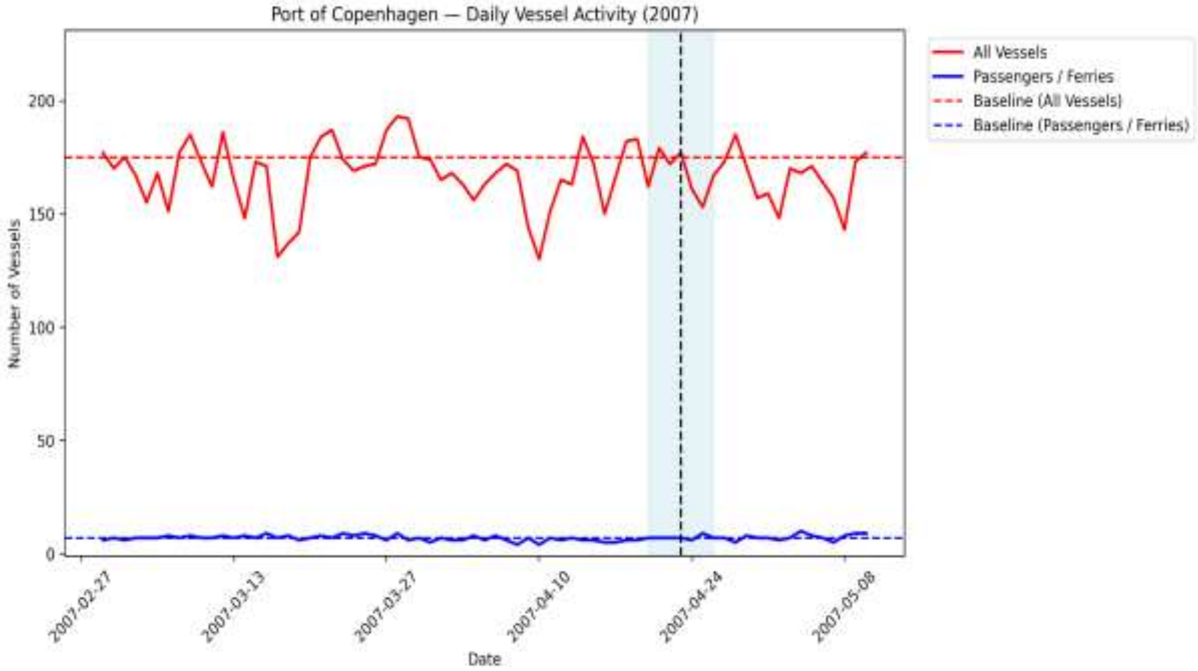
Aarhus

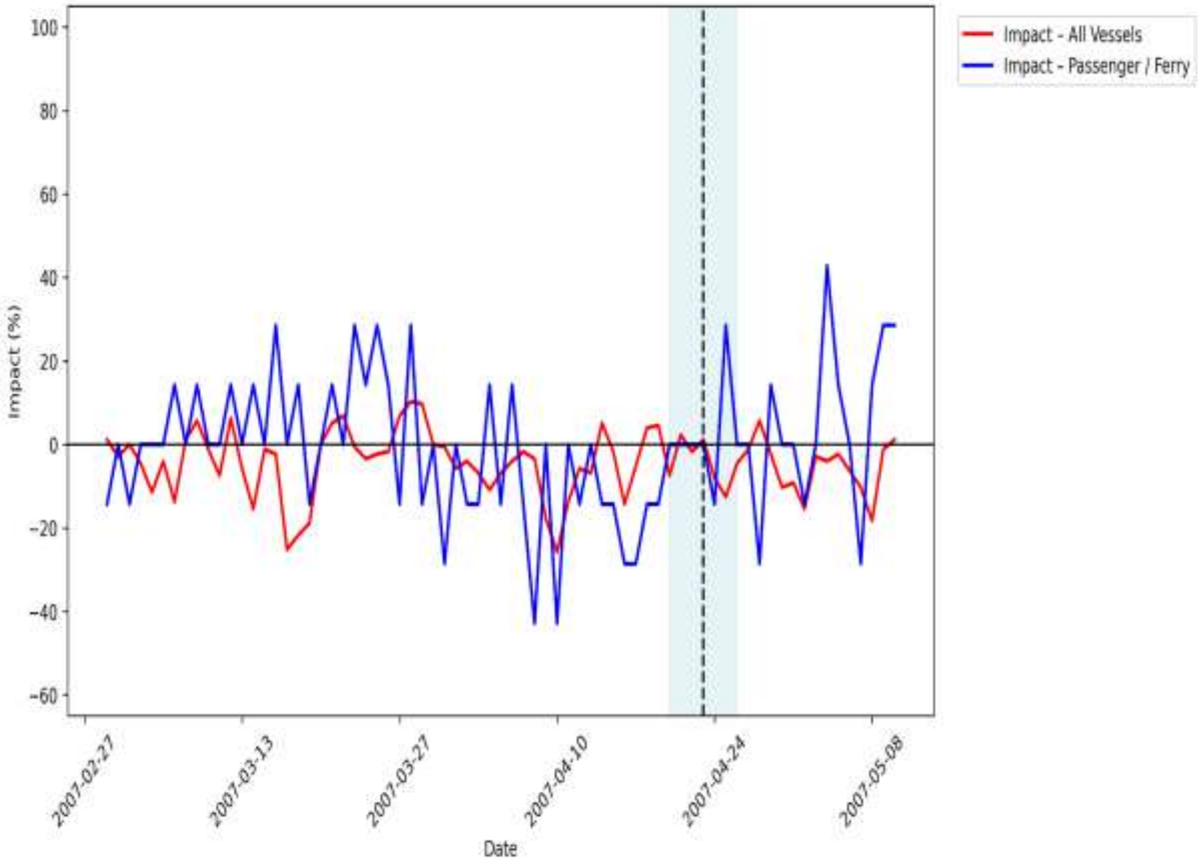


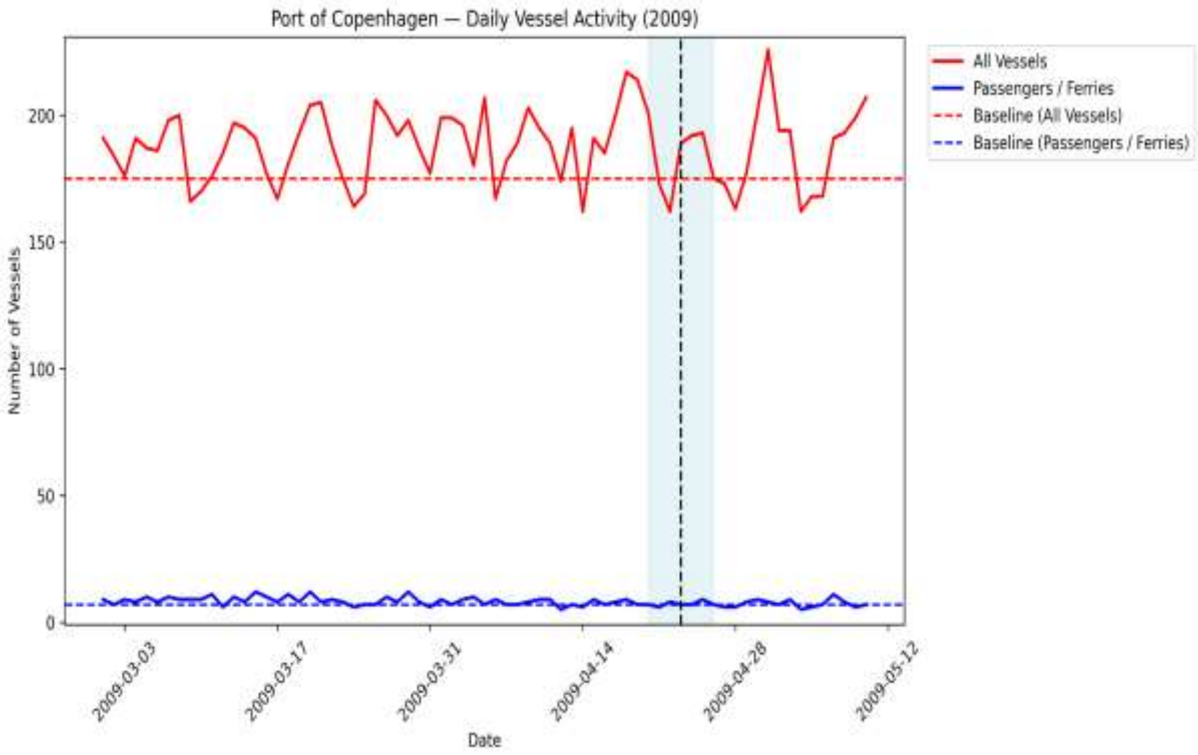


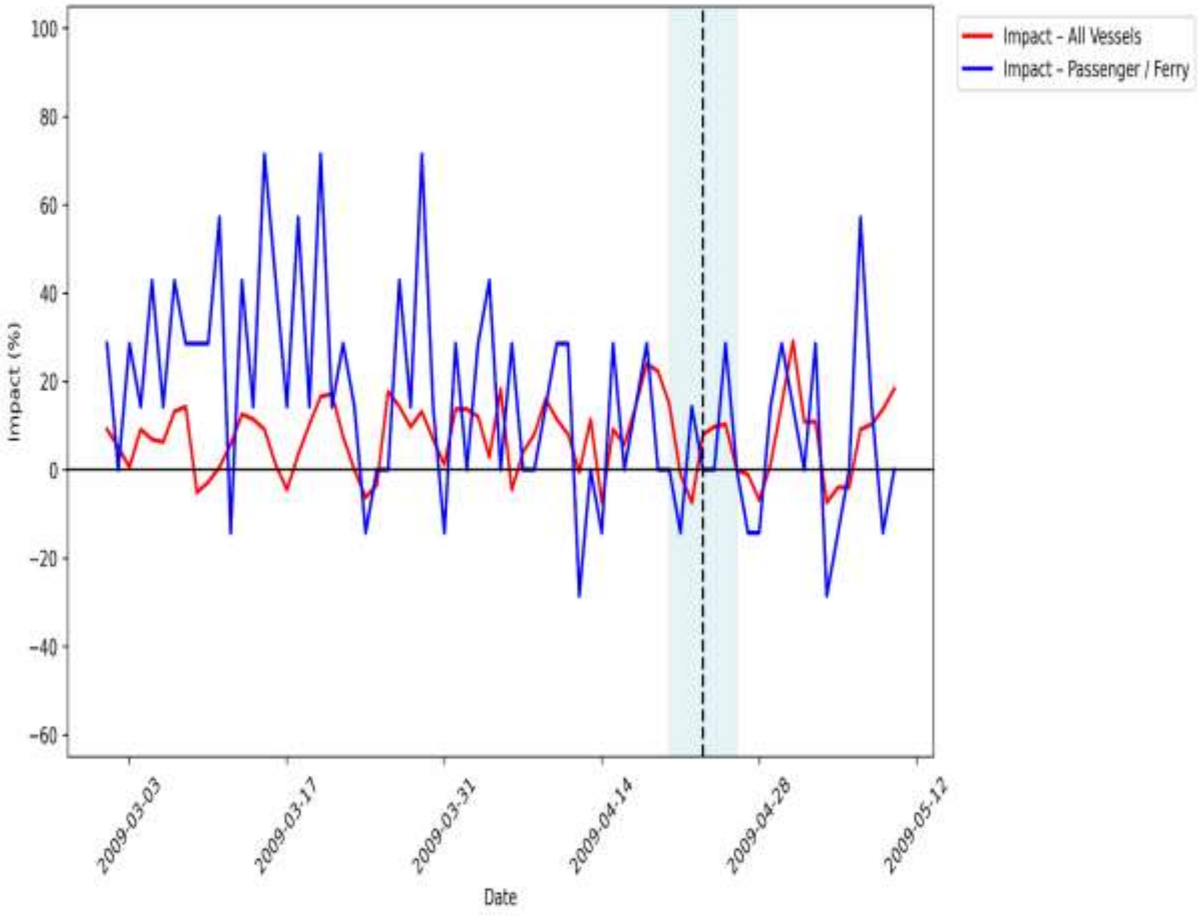

Port of Aarhus — Daily Vessel Activity (2009)
All Vessels
Containerships
Baseline (All Vessels)
Baseline (Containerships)
Number of Vessels
0
50
100
150
200
2009-03-03
2009-03-17
2009-03-31
2009-04-14
2009-04-28
2009-05-12
Date
Impact - All Vessels
Impact - Containerships
Impact (%)
100
80
60
40
20
0
−20
−40
−60
2009-03-03
2009-03-17
2009-03-31
2009-04-14
2009-04-28
2009-05-12
Date

Copenhagen


Port of Copenhagen — Daily Vessel Activity (2007)
Number of Vessels
0
50
100
150
200
2007-02-27
2007-03-13
2007-03-27
2007-04-10
2007-04-24
2007-05-08
Date
All Vessels
Passengers / Ferries
Baseline (All Vessels)
Baseline (Passengers / Ferries)


Impact (%)
100
80
60
40
20
0
-20
-40
-60
2007-02-27
2007-03-13
2007-03-27
2007-04-10
2007-04-24
2007-05-08
Date
Impact - All Vessels
Impact - Passenger / Ferry


Port of Copenhagen — Daily Vessel Activity (2009)
Number of Vessels
0
50
100
150
200
2009-03-03
2009-03-17
2009-03-31
2009-04-14
2009-04-28
2009-05-12
Date
All Vessels
Passengers / Ferries
Baseline (All Vessels)
Baseline (Passengers / Ferries)


Impact (%)
100
80
60
40
20
0
−20
−40
−60
2009-03-03
2009-03-17
2009-03-31
2009-04-14
2009-04-28
2009-05-12
Date
Impact - All Vessels
Impact - Passenger / Ferry