FEDERAL UNIVERSITY OF RIO DE JANEIRO

COPPEAD GRADUATE SCHOOL OF BUSINESS

Gabriel Serraino Moreira de Souza

Impact of COVID-19 on the efficiency of Brazil's major container terminals: a two-stage network DEA based Malmquist approach

RIO DE JANEIRO

2023

Gabriel Serraino Moreira de Souza

Impact of COVID-19 on the efficiency of Brazil's major container terminals: a two-stage network DEA based Malmquist approach

Master's thesis presented to the COPPEAD Graduate School of Business/Federal University of Rio de Janeiro, as part of the mandatory requirements in order to obtain the degree of Master in Business Administration (M.Sc.).

Supervisor: Otavio H. dos Santos Figueiredo

RIO DE JANEIRO

2023

CIP - Catalogação na Publicação

Serraino Moreira de Souza, Gabriel
S729i Impact of COVID-19 on the efficiency of Brazil’s major container terminals: a two-stage network DEA based Malmquist approach / Gabriel Serraino Moreira de Souza. -- Rio de Janeiro, 2023.
68 f.

Orientador: Otavio Henrique dos Santos Figueiredo.
Coorientador: Adriano Lauro.
Dissertação (mestrado) - Universidade Federal do Rio de Janeiro, Instituto COPPEAD de Administração, Programa de Pós-Graduação em Administração, 2023.

1. Supply chain disruption. 2. port efficiency. 3. container terminals. 4. resilience. I. Henrique dos Santos Figueiredo, Otavio, orient. II. Lauro, Adriano, coorient. III. Título.

Elaborado pelo Sistema de Geração Automática da UFRJ com os dados fornecidos pelo(a) autor(a), sob a responsabilidade de Miguel Romeu Amorim Neto - CRB-7/6283.

Gabriel Serraino Moreira de Souza

Impact of COVID-19 on the efficiency of Brazil's major container terminals: a two-stage network DEA based Malmquist approach

Master's thesis presented to the COPPEAD Graduate School of Business/Federal University of Rio de Janeiro, as part of the mandatory requirements in order to obtain the degree of Master in Business Administration (M.Sc.).

Approved by:

_______________________________________(President of the Board)
Prof. Otavio Henrique dos Santos Figueiredo, D.Sc. - Advisor
(COPPEAD/UFRJ)

____
Prof. Adriano Lauro, D.Sc. - Co-advisor
(Naval War College)

____
Prof. Peter Fernandes Wanke, D.Sc.
(COPPEAD/UFRJ)

____
Prof. Rafael Garcia Barbastefano, D.Sc.
(CEFET/RJ)

____
Prof. Vanessa de Almeida Guimarães, D.Sc.
(CEFET/RJ)

Rio de Janeiro

2023

DEDICATION

To my parents, for always believing in me.

ACKNOWLEDGMENTS

I sincerely appreciate the Brazilian Navy’s effort to sponsor this remarkable learning experience.

I would also like to thank the maritime industry professionals who gladly provided significant data and information for this research.

To my co-advisor: your theme suggestion, knowledge sharing and valuable insights during this past year were decisive to the elaboration of this work. I can’t thank you enough.

Finally, to my advisor, faculty, academic staff and colleagues: please accept my deepest gratitude for the indispensable support throughout this journey.

RESUMO

SOUZA, Gabriel. **Impact of COVID-19 on the efficiency of Brazil’s major container terminals: a two-stage network DEA based Malmquist approach**. Rio de Janeiro, 2023. 68 p. Thesis (Master’s Degree in Business Administration) - COPPEAD Graduate School of Business, Federal University of Rio de Janeiro, Rio de Janeiro, 2023.

A pandemia de COVID-19 não apenas representou um grave problema de saúde, mas também um forte golpe na economia global. Devido a bloqueios rígidos, as atividades manufatureiras e logísticas foram suspensas em todo o mundo e impactando diferentes setores, dentre eles as cadeias de abastecimento marítimas. Este estudo aplica a Análise Envoltória de Dados (DEA) em rede de dois estágios, associada ao índice de Malmquist, a fim de analisar o impacto da pandemia de COVID-19 na eficiência dos 20 principais terminais de contêineres brasileiros. O modelo utiliza três dados de entradas (área total, número de berços e área de armazenagem), um dado de entrada intermediário (número de atracações) e um dado de saída (movimentação de contêineres) considerando a infraestrutura física e a consolidação de embarques como os dois *drivers* de eficiência. As descobertas indicam que a pandemia de COVID-19 não teve um impacto significativo nos terminais da amostra. Os resultados podem fornecer *insights* para futuras políticas governamentais e estratégias de gestão destinadas a melhorar a eficiência, robustez, resiliência, competitividade e segurança dos terminais de contêineres brasileiros frente a eventos que provocam disrupção em cadeias de suprimentos.

Palavras-chave: Disrupção da cadeia de suprimentos; eficiência portuária; terminais de contêineres; resiliência.

ABSTRACT

SOUZA, Gabriel. **Impact of COVID-19 on the efficiency of Brazil's major container terminals: a two-stage network DEA based Malmquist approach**. Rio de Janeiro, 2023. 68 p. Thesis (Master's Degree in Business Administration) - COPPEAD Graduate School of Business, Federal University of Rio de Janeiro, Rio de Janeiro, 2023.

The COVID-19 pandemic not only represented a serious health issue but also a severe hit on global economy. Due to strict lockdowns, manufacturing and logistic activities have been suspended worldwide impacting different sectors, including maritime supply chains. This study applies a two-stage network Data Envelopment Analysis (DEA) with a Malmquist index approach to 20 major Brazilian container terminals in order to analyze the impact of COVID-19 pandemic on their efficiency. The model uses three inputs (total area, number of berths and warehousing area), one intermediate input (shipment frequency) and one output (container throughput) considering physical infrastructure and shipment consolidation as the two efficiency drivers. The findings indicate the onset of COVID-19 pandemic did not have a significant impact on the sample's terminals. Results can provide insights for future government policies and management strategies aimed at improving Brazilian container terminals' efficiency, robustness, resilience, competitiveness and security ahead of supply chain disruptive events.

Keywords: Supply chain disruption; port efficiency; container terminals; resilience.

LIST OF FIGURES

FIGURE 1. GLOBAL SC LAYERS……………………………………...………..………14

FIGURE 2. GEOGRAPHICAL LOCATION OF THE 20 BRAZILIAN CONTAINER TERMINALS………………………………………………………………………………30

FIGURE 3. TWO-STAGE NETWORK DEA MODEL APPLIED………………………….30

FIGURE 4. PHYSICAL INFRASTRUCTURE EFFICIENCY X SHIPMENT CONSOLIDATION EFFICIENCY……………………………………………………..….34

FIGURE 5. PROBABILITIES SCORES…………….……………………..….…………..….35

FIGURE 6. CONSOLIDATION OF ALL EFFICIENCY LEVELS………..…………..….35

FIGURE 7. MALMQUIST INDEX, TECHNICAL CHANGE AND EFFICIENCY CHANGE…………………………………………………………………..……….…..….40

LIST OF TABLES

TABLE 1. MAIN BENCHMARKING TECHNIQUES/METHODOLOGIES…………...…23

TABLE 2. COMPILATION OF INPUT, INTERMEDIATE INPUT/OUTPUT AND OUTPUT VARIABLES …………………….…………………...…………………………..31

TABLE 3. TWO-STAGE NETWORK DEA BASIC STATISTICAL SAMPLES……….....32

TABLE 4. EFFICIENCY SUMMARY FOR EACH TERMINAL…………………...…..….36

TABLE 5. MALMQUIST INDEX BASIC STATISTICAL SAMPLES…………………....38

TABLE 6. MALMQUIST INDEX, TECHICAL CHANGE AND EFFICIENCY CHANGE SUMMARY FOR EACH TERMINAL……………………………………………………....40

TABLE 7. UNPAIRED TWO-SAMPLES WILCOXON TEST RESULTS………………..42

LIST OF ABBREVIATIONS

ANTAQ	National Water Transport Agency
BCC	Banker, Charnes and Cooper
BiO-MCDEA	Bi-objective Multiple Criteria Data Envelopment Analysis
BPR	Business Process Re-engineering
BSC	Balanced Scorecard
BTP	Brasil Terminal Portuário
COLS	Corrected Ordinary Least Squares
CONPORTOS	National Commission for Public Security in Ports, Terminals and Waterways
COVID-19	Coronavirus disease of 2019
CPPI	Container Port Performance Index
CRM	Customer Relationship Management
CRS	Constant Return to Scale
DEA	Data Envelopment Analysis
DMU	Decision-Making Units
DP	Dubai Ports
EC	Efficiency Change
ECHO	European Commission Humanitarian Aid and Civil Protection Department
ECLAC	Economic Commission for Latin America and the Caribbean
EEA	Engineering Economic Analysis
ERP	Enterprise Resource Planning
ESG	Environmental, Social and Governance
FDH	Free Disposal Hull
FDI	Foreign Direct Investment
FEMA	Federal Emergency Management Agency
FEU	Forty-foot Equivalent Unit
GDP	Gross Domestic Product
ICT	Information and Communication Technology
ILO	International Labour Organization
IMF	International Monetary Fund
IMO	International Maritime Organization
IoT	Internet of Things
ISPS	International Ship and Port Facility Security Code
LPI	Logistics Performance Index
LSCI	Liner Shipping Connectivity Index
M	Malmquist index
MCDEA	Multiple Criteria Data Envelopment Analysis
MDA	Maritime Domain Awareness
MFP	Multifactor Productivity

NDRS	Non-Decreasing Return to Scale
NIRS	Non-Increasing Return to Scale
NPRN	National Port Readiness Network
OECD	Organisation for Economic Co-operation and Development
PEST	Political, Economic, Social and Technological
PFP	Partial Factor Productivity
PPI	Port Performance Indicators
PPP	Public-Private Partnerships
SC	Supply Chains
SFA	Stochastic Frontier Analysis
SFP	Single-factor Productivity
SME	Small and Medium Enterprises
TC	Technical Change
TEU	Twenty-foot Equivalent Unit
TFP	Total Factor Productivity
TQM	Total Quality Management
UDEA	Uncertainty Data Envelopment Analysis
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
US	United States
USTRANSCOM	United States Transportation Command
VRS	Variable Return to Scale
WEF	World Economic Forum
WHO	World Health Organization

CONTENTS

1	**INTRODUCTION**	**1**
2	**LITERATURE REVIEW**	**5**
2.1	MARITIME SUPPLY CHAINS	5
2.1.1	Maritime Supply Chain Security	6
2.2	SUPPLY CHAIN RISK MANAGEMENT	8
2.2.1	Supply Chain Disruption	9
2.2.1.1	*Addressing Supply Chain Disruption*	11
2.3	PORTS	13
2.3.1	Container Ports	16
2.4	PORT CONGESTION	19
2.5	PORT PERFORMANCE	20
2.6	PORT EFFICIENCY	22
3	**METHODOLOGY**	**25**
3.1	DATA ENVELOPMENT ANALYSIS (DEA)	25
3.1.1	Two-stage Network DEA with Malmquist index	28
3.2	DATA AND VARIABLES SELECTION	29
4	**RESULTS AND DISCUSSION**	**32**
4.1	TWO-STAGE NETWORK DEA	32
4.1.1	March 2018 to February 2019	32
4.1.2	March 2019 to February 2020	33
4.1.3	March 2020 to February 2021	33
4.1.4	March 2021 to February 2022	33
4.1.5	Two-stage Network DEA Special Cases	34
4.1.6	Two-stage Network DEA Stages Representation	34
4.2	MALMQUIST INDEX	38
4.2.1	March 2018 to February 2019-March 2019 to February 2020 ("before" the pandemic)	38

4.2.2 March 2019 to February 2020-March 2020 to February 2021 ("during" the pandemic) 38
4.2.3 March 2020 to February 2021-March 2021 to February 2022 ("after" the pandemic) 39
4.2.4 Malmquist Index Special Cases 39
4.2.5 Malmquist Index Representation 39
4.3 UNPAIRED TWO-SAMPLES WILCOXON TEST 41
4.4 DISCUSSION 42

5 CONCLUSION 44

REFERENCES 46

APPENDIX A-Input, Intermediate Input and Output Variables (March 2018 to February 2019) 65
APPENDIX B-Input, Intermediate Input and Output Variables (March 2019 to February 2020) 66
APPENDIX C-Input, Intermediate Input and Output Variables (March 2020 to February 2021) 67
APPENDIX D-Input, Intermediate Input and Output Variables (March 2021 to February 2022) 68

1 INTRODUCTION

In recent decades, society has witnessed a growing globalization process. Al-Rodhan and Stoudmann (2006), define globalization as “a process that encompasses the causes, course, and consequences of transnational and transcultural integration of human and non-human activities” (p. 5). Hence integration of all sorts of human activities (i.e., geopolitical, economic, social) in an ever-increasing globalized world is common trend. In the realm of international trade, supply chains (SC) tend to stretch to almost all parts of the globe and even connect to each other forming SC networks. Ultimately, globalization and competitive pressure paved the way to more complex and dynamic SC (Christopher, Peck & Towill, 2006; Creazza, Dallari & Melacini (2010).

In this context, maritime transportation plays a key role in global overseas trade. Being a cost-effective and efficient mode of international transportation for most goods, it represents more than 80 per cent of global trade to people and communities all over the world according to the International Maritime Organization (IMO, 2022). It is also an integrated system composed of several elements (i.e., seaports, freight forwarders, logistics companies, shipping management companies, etc. (de Langen & van der Lugt, 2017), one of the most important being the seaport.

Ports are key components of the global maritime SC. That is the reason why seaport countries increasingly invest in maritime transport as shown by growing number and specialization of port terminals, improvement of machinery and rising cargo volumes from distant countries - all of which ultimately benefit both the port’s state and its population (Žimkus, 2016). More specifically, “a look at how the various market segments have evolved since 1990 shows that growth in maritime trade […] has been sustained by bullish trends in containerized trade volumes starting in the 2000s, coinciding with the wave of hyperglobalization” (UNCTAD, 2020).

As a result, port efficiency measurement studies can provide insights on how to not only improve port performance but also protect – or at least mitigate – the effects of SC disruptive events, the latter deriving from either natural (i.e., Indian Ocean’s earthquakes and tsunamis in 2004 and 2011) or man-made (i.e., 2008-2009 economic crisis) calamities. The outbreak of an infectious disease like COVID-19, for instance, has not only put human lives in danger but also taken its toll on economic activities like manufacturing operations, SC and logistics, among others (Dolgui, Dimitri & Boris 2020; Golan, Laura & Igor, 2020; Hobbs, 2020; Iyengar, Vaishya, Bahl & Vaish, 2020; Linton & Vakil 2020; Remko, 2020; Rowan & Laffey 2020).

The Economic Commission for Latin America and the Caribbean (ECLAC)'s 2020 Port Report (2021) highlights a few elements that, combined, set COVID-19 pandemic apart from previous SC disruptive events. To begin with, crippling economic effects of the 2008–2009 crisis had never completely disappeared, creating a time of relative economic and logistic weakness that favored the impacts of the COVID-19 pandemic. In terms of speed of development, global markets were already being damaged around two to three months after the beginning of the pandemic while the 2008-2009 crisis' worst effects were only noticed many months later. Also, in terms of extent of the effects, the COVID-19 pandemic is reckoned a global crisis (roughly 90 per cent of the world's economies were highly affected) whereas previous ones had a more regional impact. Finally, the intensity of the effects on economic trade during this pandemic is almost unprecedented, with the World Bank (2020) having announced this is the largest decline in international trade since World War II and the largest relative descent in GDP in Latin America since 1901.

The COVID-19 pandemic's effects on global maritime SC are unfolding in several phases. First, a supply shock in China in early 2020 (January to March) due to the recurrent decreased Chinese production during New Year's Eve and the country's lockdown measures. Then, a global demand shock in March that disseminated throughout the SC as a result of widespread lockdowns that shifted consumption towards more essential goods (i.e., clothes, food), revealing last-mile distribution vulnerabilities and plummeting commodities prices such as petroleum. Lastly, a period of deferred demand uncertainty as COVID-19 restrictions gradually started to ease worldwide (Notteboom, Pallis & Rodrigue, 2020).

Weekly updates on massive traffic jams at the worlds' busiest port complexes have made headlines in numerous media outlets. Shanghai, the world's busiest and most important seaport, has not only suffered with recent "surging" port congestion across China (i.e., ships re-routing from neighboring ports like Ningbo) but also with rising Covid cases and lockdowns that have caused additional cargo delays and put more pressure on global SC (Bloomberg, 2022; CNN Business, 2022; The Loadstar, 2022).

The Los Angeles-Long Beach port complex, the ninth largest in the world and largest in United States, registered in October 2021 a record of 100 ships at anchor waiting to enter and unload (against an all-time average of 17), forcing the White House to strike a deal with Los Angeles Port Authority in order to establish around-the-clock operations (ABC7 Los Angeles, 2021; The Guardian, 2021).

The Port of Rotterdam, Europe's largest, will likely continue to suffer from congestion and bottlenecks in container traffic movement amid efforts on improving schedule reliability while global fleet of ships has been reduced by 25 per cent due to aforementioned longer waiting times around Asia and United States (US) key ports (India Times, 2022).

ECLAC's 2020 Port Report (2021) brings some relevant figures on maritime transportation as a result of COVID-19. Total international trade by water transport decreased to approximately 11.5 billion tonnes in 2020 after reaching an all-time high of almost 12 billion tonnes in 2019, representing a year-on-year drop of -3.8 per cent according to the Seaborne Trade Monitor. In terms of global container trade measured in twenty-foot equivalent units (TEUs), the Container Trade Statistics database revealed how this market segment was generally impacted in 2020: year-on-year TEU declines at the start of 2020 when compared to the previous year, followed by a sharp drop around the end of the first semester and a gradual return to just under 2019 levels throughout the second semester (0.9% annual reduction) (ECLAC, 2021).

Rising container freight rates have been another serious concern. Labour and equipment shortages, supply and demand mismatches and on-and-off Covid-19 governmental measures and restrictions have led industry insiders to expect shipping and logistics costs to remain high along 2022 and into 2023 (Freightos, 2022; Lind, Lehmacher, Hoffmann, Jensen, Notteboom, Rydbergh, Sand, Haraldson, White, Becha, & Berglund, 2022).

The United Nations Conference on Trade and Development (UNCTAD)'s Review of Maritime Transport 2021 reveals short and long-run effects of the COVID-19 pandemic's impact. On one hand, as container trade started to pick up late 2020, those supply-side constraints which increased shipping and logistics costs gradually undermine service reliability and value chain operations. In the long run, on the other hand, as these problems tend to be solved, other structural factors such as patterns of globalization, changes in consumption habits, growth of ecommerce, global energy transition and sustainability will ultimately exert greater influence on the overall outcome (UNCTAD, 2021).

The same document also highlights the need for greater preparedness, risk management and resilience. Having been amplified by other incidents that created transport bottlenecks (i.e., the blocking of the Suez Canal by Ever Given ship in March 2021), unveiling SC risks and vulnerabilities, COVID-19 pandemic's disruptive power revealed that reorganizing global maritime transport networks while redesigning business models are imperative to building future SC resilience (UNCTAD, 2021). Consequently, improving the ability of ports to plan activities, monitor performance and withstand competitive pressure while anticipating maritime market changes becomes essential (Liebuvienè and Cˇižiu¯nienè, 2022).

The aim of this master thesis is to analyze the impact of the COVID-19 pandemic on the efficiency of Brazil's major container terminals. It applies Liang, Cook and Zhu's (2008) and Zhu's (2011) network-DEA centralized efficiency model in two stages by considering physical infrastructure (Alderton, 2008) and shipment consolidation (Wanke, Barbastefano & Hijjar, 2011) as the two efficient drivers and assuming shipment frequency per year as the critical intermediate output (Wanke, 2013). A Malmquist index approach is incorporated so as to allow for a dynamic efficiency evaluation between March 2018 and February 2022. The researcher hopes not only to identify which Brazilian container port terminals have better performed during this SC crisis but also to indirectly contribute to asset capability/performance analysis carried out by Brazilian government's main strategic sectors (i.e., economy, defense, infrastructure, commercial trade).

The remainder of the study is organized as follows: Section 2 covers the literature review while Section 3 outlines the methodology and data collected. The empirical results are, then, presented and discussed in Section 4. Finally, the study's conclusions, limitations and future prospects are indicated in Section 5.

2 LITERATURE REVIEW

This section covers the literature review on SC as follows: definition of SC and related topics (SC management, maritime SC and SC risk management), SC disruptions and how to address them, and definition of ports and containers followed by related topics (port congestion, port performance and efficiency).

2.1 MARITIME SUPPLY CHAINS

Coined in the 1980s and widely spread across the 1990s during a time of increased focus on improving the efficiency of the flow of resources among organizations (Christopher and Peck, 2003), the term "supply chain" can be described as the combination of "all parties involved, directly or indirectly, in fulfilling a customer request […] includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers, and even customers themselves" (Chopra and Meindl, 2013). Oliveira, Lima and Montevechi (2016, p. 166) further define SC as "an aggregate set of value chains linked by inter-organizational relationships, both upstream and downstream of the leader company in order to deal with all the flows involved (cash, material, goods, and information)". Ultimately, a SC's role is to add value to a product along its way through different locations (Janvier-James, 2012).

Being a holistic approach to management activities that surpass company boundaries, "supply chain management" refers to the "management of the interconnection of organizations that relate to each other through upstream and downstream linkages between the processes that produce value to the ultimate consumer in the form of products and services." (Slack, Brandon-Jones, & Johnston, 2013, p. 406). This is consistent with Langley, Coyle, Gibson, Novack, and Bardi. (2008) conclusion that the rationale for this concept is the opportunity for better cost reductions and customer service through managing SC networks, resulting in the improvement of a firm's competitiveness in the global marketplace.

In other words, SC management applies a systems approach to the coordination of the flow of products and services between organizations that form a SC (SCM Globe, 2020). A firm's success can be, consequently, attributed to its ability to integrate both intra and inter-firm processes in order to foster efficient and effective optimization of goods, services and information when coordinating the business relationships network among SC members (Bhatnagar and Teo, 2009; Childerhouse and Towill, 2003; Disney and Towill, 2003; Yuen and Thai, 2017).

Maritime SC play a vital role in global trade development. Frankel (1999) outlines that maritime SC basically integrate maritime services and transshipment functions to maritime distribution functions. Chryssolouris, Makris, Xanthakis and Mourtzis (2004) further point out that maritime SC involve different interrelated partners performing either manufacturing or distribution activities. These views suggest that maritime SC consider the interests of all its components and, therefore, it is expected that port authorities, shipping organizations, SC partners and import-export firms builds relationship among themselves (Osobajo, Koliousis & McLaughlin, 2021).

2.1.1 Maritime Supply Chain Security

There is prominent strategic value in a country's maritime transport of goods, services and people, both civilian and military. The US Department of Transportation's National Port Readiness Network (NPRN) is a cooperative body in charge of ensuring readiness of commercial ports in an effort to support armed forces' troops deployment and supplies provision during regular operations or national defense emergencies. Organized around four major categories of national security issues related to transportation (transportation supply securement, transportation readiness maintenance, transportation vulnerability reduction and illegal use of transportation), the NPRN consists of numerous government bodies, many of them military.

Not surprisingly, the Biden administration recently appointed Retired General Stephen Lyons to take over the role of Port and Supply Chain Envoy to the White House's task force created to engage SC disruptions caused by the pandemic; Ret. Gen. Lyons had been previously serving as the commander of the US Transportation Command (USTRANSCOM), one of NPRN's federal military organizations (Rodrigue & Slack, 2002; United States Department of Transportation, 2021; Landis, 2022).

The UK is another major geopolitical power who is committed to creating a more secure and prosperous maritime sector. An island nation deeply connected to the ocean, the UK's National Strategy for Maritime Security establishes five strategic objectives, as follows: protecting homeland, responding to threats, ensuring prosperity, championing the nation's values and supporting a secure, resilient ocean.

The first two deserve to be further addressed. UK government believes an effective response to threats like drug trafficking, terrorism and illegal migration necessarily employs Maritime Domain Awareness (MDA) capabilities, creates a secure environment for navigation, defends the integrity of maritime interests from state threats (i.e., espionage, sabotage, data theft) and monitors any national security risks derived from Foreign Direct Investment (FDI) into UK infrastructure and assets (including intellectual property) to which the UK might be exposed (United Kingdom, 2022).

At the same time, maritime SC worldwide are becoming increasingly dependent on digitalization and automation solutions – core elements of logistics 4.0. Through the use of Big Data and Internet of Things (IoT), data gathering and monitoring systems, automated guided vehicles and pallet sensors have proliferated across day-to-day operations transforming ports into maritime information-network hubs. Such phenomenon leaves them highly vulnerable to cyberthreats, which also draws attention of UK government officials who consider it a matter of national security (Chelin & Reva, 2020).

Brazil's corresponding government body is the National Commission for Public Security in Ports, Terminals and Waterways (Conportos). Created in 1995, this commission is also comprised by a multitude of federal agencies such as the Ministry of Infrastructure, Ministry of Foreign Affairs, Ministry of Defense, ANTAQ and so on. Some of its responsibilities are to establish and periodically assess public safety projects and procedures, monitor occurrences of criminal offenses, ensure compliance with both foreign and domestic legislation, treaties, conventions and international codes (such as the ISPS, among others.

Regarding the latter feature, the country presently complies with IMO's International Ship and Port Facility Security Code (ISPS); created in 2004, it basically institutes an international framework fostering cooperation between contracting governments, government agencies and the shipping and port industries in assessing and implementing preventive security measures against potential security threats to ships or port facilities used for international trade. Both Conportos and the Brazilian Navy have active roles in respectively certifying ports and ships entitled to ISPS international accreditation (Segrini, 2017; IMO, 2022a; Brasil, 2022c).

It is worth mentioning that, on a broader perspective, the Brazilian maritime SC contributes to enhance the country's strategic presence not only in its 5,7 million square kilometers exclusive economic zone (also known as Blue Amazon or "Amazônia Azul") but also in its strategic geopolitical environment: South America, the Southern Atlantic region, African West Coast and Antarctica (Lima, Milani, Duarte, Albuquerque, Acácio, Carvalho, Medeiros, Novacek, Costa, Costa & Lemos, 2017; Brasil, 2022d). Within this framework the concept of "indirect protection mechanism" comes to the fore. Any state action in the field of national development devoid of a public safety role that, indirectly, plays a fundamental role in the wider context of state security contributing to delay, mitigate and even eliminate potential problems (thus avoiding the undesirable securitization of issues) is regarded as an indirect protection mechanism (Abreu, 2018).

That is to say, whenever a given situation is mismanaged a state can be compelled to securitize problems that might be perceived as threats, spending resources on an emergency basis and usually employing security forces to maintain public order. Following this logic, the maritime port sector and overall waterway transport, key components of Brazil's public transport policy, are surely considered indirect mechanisms for the protection of the nation's strategic geopolitical environment (Perni, 2019).

As for the country's sovereignty and national security issues, mention must be made to the Southeast/South macro-region's importance. Home to numerous industrial complexes, a relevant consumer market and Brazil's main ports (most notably those located in the Santos area), it is responsible for over 80 per cent of the national container volume. Most of the nation's military logistics support missions departure from this region via cabotage navigation to places with precarious access by other modes, such as the Amazon region. Not surprisingly, it is also where some of the country's most relevant shipowners-owned terminals are found, making it an ideal environment for inter and intra-port competition, not to mention FDI attraction (Brazil, 2022b); one example of the latter is China: following its Belt-and-Road initiative, this Asian country has expanded its geopolitical influence worldwide by means of maritime infrastructure investments overseas (i.e., Paranaguá, held to be South America's largest container terminal).

2.2 SUPPLY CHAIN RISK MANAGEMENT

As more organizations take part in a SC network, there is a rise in the number of business interactions which makes SC management an increasingly complex challenge. Thus, it is comprehensible that members of a SC dedicate increasing resources to SC risk management, the set of risk identification, analysis, assessment and monitoring activities conducted in order to implement strategies that ultimately reduce SC vulnerabilities (Jüttner, Peck & Christopher, 2003). With regards to the very notion of risk, Pfohl, Ko˙hler, & Thomas (2010) explain there are two ways in which to define risk, one related to its causes and the other to its effects. The former focuses on a decision-making unit's deficit of information concerning prospective events (Miller, 1992); the latter, on the other hand, centers on the consequences of a decision, whether it may be a wrong decision's resulting hazards (Imboden, 1983) or as a variation in the distribution, potential and likelihood of possible outcomes (March and Shapira, 1987).

Waters (2007) makes his contribution by defining SC risk as essentially any event that might affect and possibly disrupt the planned flow of the movement of materials from initial suppliers to final customers. Also, while some authors tend to categorize different types of SC risks (Pfohl, Gallus & Ko˙hler, 2008), Waters presents three, as follows: risks within a focal company, risks outside of this company and within the SC, and risks outside of the SC that affect the focal company from their respective place of origin (2007). Ultimately, SC risks may affect the goal achievement in terms of time, cost, quality and end customer value of single companies and even entire SC (Pfohl et al., 2010).

There has been a growing interest in SC risk in the academic field over the past two decades as recalled by Pournader, Kach and Talluri (2020) with studies gravitating towards two different areas, one of them aiming at providing frameworks for identifying, categorizing, assessing and managing SC risk and another one focusing on certain types of risks such as information sharing risk (Colicchia, 2019), sustainability-related supplier risk (da Silva, Ramos, Alexander & Jabbour, 2020), or even climate change (Ghadge, Wurtmann & Seuring, 2020).

More specifically, Blackhurst, Dunn and Craighead (2011) have noticed a focus shift on SC design from service optimization and cost reduction to SC robustness and SC resilience – all attributed to the rising awareness about SC risk. About these two expressions, Madzimure (2020) drew from the theories of Meepetchde and Shah (2007), Kwak, Seo and Mason (2017) and Hove-Sibanda, Sibanda and Pooe (2017) to define SC robustness as "a proactive strategy done by a firm in advance for a supply chain to resist change and still achieve its acceptable performance." (p. 139); in turn, Hohenstein et al. (2015) turned to Rice and Caniato (2003), Christopher and Peck (2004), Jüttner and Maklan (2011) and Chopra and Sodhi (2014) to explain, based on the premise that not all potential risks can be avoided, that SC resilience "encompasses the ability to prepare for unforeseen disruptions and to respond and recover from them faster than competitors do" (p. 91).

2.2.1 Supply Chain Disruption

It is important to differentiate SC risk from SC disruption risk. While the former category relates to risks that are inherent to any SC consisted of companies dispersed across the globe, the latter only refer to those capable of imposing serious damages to regular business activities; that is, capable of threatening the existence of one or more SC components or even preventing the SC from temporarily achieving its operational goals altogether (Bugert and Lasch, 2018; Heckmann, Comes & Nickel, 2015).

To gain competitive advantage, firms will apply the best possible operational management practices given a certain business context and adapt them as the context changes, especially during turbulent times (Birkie *et al.*, 2017); it comes as no surprise, then, that the recent upsurge in frequency and severity of unanticipated SC disruptions points towards relevant changes in the global business environment.

There are different ways in which to characterize this phenomenon. Hendricks and Singhal (2003) suggest that a SC disruption can be thought of a sudden mismatch between supply and demand affecting profitability and general operations, with such mismatches being minimized by ways of better forecasting and planning systems such as Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM). Coming from a different standpoint, Melnyk et al. (2009) consider SC disruption a matter of "cause and effect" where one triggering event at one point in the SC negatively affects the performance of one or more components of that particular SC.

Complexity plays a key role in these situations. In accordance with Birkie *et al.* (2017), managing SC disruption in a resilient fashion requires dealing with various forms of complexity. A number of authors (Bode and Wagner, 2015; Collinson and Jay, 2012; Manuj and Sahin, 2011) have considered a company's organizational design, SC network, product portfolio and other similar factors as potential sources of complexity in any given SC while others (Bode and Wagner, 2015; Craighead et al., 2007) have highlighted the importance of taking the complexity factor into consideration when dealing with SC disruptions.

Firms usually apply conceptual SC disruption risk models that implicitly or explicitly consider SC disruption risks. The former ones have a more problem-specific orientation (Heckmann *et al.*, 2015) and usually aim at issues like supplier selection, facility location, SC network design and concepts of information sharing such as bullwhip effect, planning and forecasting (Fahimnia, Tang, Davarzani & Sarkis, 2015). The latter, on the other hand, focus on the SC behavior as a whole by analyzing the interdependencies among SC risks and their repercussions (Garvey, Carnovale & Yeniyurt, 2015) – something which may sound more abstract but is useful to identify SC vulnerabilities and, thus, shift the attention to specific problems (Bugert and Lasch, 2018).

When facing a SC disruption, response time is crucial (Bode, Wagner, Petersen & Ellram, 2011). Consequently, in a business environment where the global SC is deemed "fragile" due to the adoption of SC improvement techniques (i.e., Lean management, Total Quality Management, time-based competitions), many companies have not only established a risk management infrastructure consisted of risk managers, security procedures, emergency operations centers, to cope with SC disruptions (Chopra and Sodhi, 2014; Manuj and Mentzer, 2008; Revilla and Sáenz, 2011; Zsidisin, Melnyk & Ragatz, 2005) but also fostered collective cooperation both upstream (i.e., suppliers) and downstream (i.e. logistics service providers) the SC in order to effectively respond to SC disruptions; if properly implemented, these measures are capable of even reducing SC disruptions' frequency, as demonstrated by Revilla and Saenz (2017).

It is important to add the role of risk management in encouraging SC resilience and robustness when absorbing SC disruptions' impacts. On this matter, El Baz and Ruel (2021) state that, by adopting SC risk management practices, firms can mitigate SC disruptions and consequently have greater chances of maintaining SC performance (robustness) and/or recovering performance after suffering disruption effects (resilience). Therefore, in order to see potential SC resilience and robustness improvements, port authorities should prioritize risk identification procedures given their influence on the other maritime SC risk management practices.

There has been a growing debate over deglobalization fueled by SC disruptions and the sudden awareness related to high dependency of low cost, efficient means of production and transportation over the years. SC regionalization in a quest for maintaining SC viability appears to be the word of the day; temporary sourcing diversification taking into account product and process specificity rekindles an interesting debate over a corporation's recovery alternatives.

These are mere symptoms of a worldwide effort to build SC resilience while assuming uncertainty as the only constant in today's global trade environment. No wonder have organizations incrementally ramped up resilience investments, adopted end-to-end approaches and moved from a just-in-time to a just-in-case mindset. Although these sourcing and operational adjustments may represent increasing costs and higher prices of goods – ultimately boosting inflation and leading to relevant implications for global economy, they are welcome contributions to more resilient and robust supply chains. (Eastwood, 2002; Guidorizzi *et al.*, 2022; Smialek & Swanson, 2022; Whitney, Luo & Heller, 2014).

2.2.1.1 *Addressing Supply Chain Disruption*

As mentioned before, SC disruptions can occur as a result of unforeseen events that negatively impact the normal flow of goods/services/information (Kleindorfer and Saad, 2005) such as natural disasters, supply shortages, demand shifts, labor disputes and quality problems (Chopra and Sodhi, 2004). Birkie, Trucco and Campos (2017) add that no matter the exact primary location of a SC disruption, its final business consequence can be detected either close or far away.

In light of these events, governmental bodies and policy makers have raised concerns during recent years over possible disruptions to the stability of the flow of goods, services and information as the global SC network density grows. On this matter, Carvalho, Nirei, Saito, and

Tahbaz-Salehi (2021) point out that policy initiatives at different levels are based on the premise that SC shocks (i.e., natural disasters, cyberattacks, terrorism) can propagate throughout business environments due to input-output linkages between firms and potentially cause macroeconomic damages. For instance, the World Economic Forum (WEF) (2012) recommends that, to cope with network vulnerabilities such as fragmentation along the value chain, extensive contracting and availability of shared information, top public/private management should prioritize actions like trusted network building across business and government, effective risk legislation and incentivization, and appropriate data and information sharing across SC.

The European Commission (2013) argues that integrated risk management solutions are necessary to face multiple challenges to the region's SC in the hopes of securing the well-being of citizens along with the European Union's economic interests. In turn, the US Government's "National Strategy for Global Supply Chain Security" (White House, 2012) is essentially based on two main goals: the promotion of an efficient and secure movement of goods, and the fostering of a resilient supply chain. Scholten, Scott and Fynes. (2014) say that practical guidelines on how to manage SC disruptions are provided by government agencies such as the Humanitarian Aid and Civil Protection Department of the European Commission (ECHO) and the Federal Emergency Management Agency (FEMA) in the USA.

Following the official announcement of a COVID-19 pandemic outbreak by the World Health Organization (WHO) in March 11th 2020 (WHO 2020), impacts not only to healthcare systems but also on global economy as well as on manufacturing and logistics activities have become a primary concern of governmental authorities (Al-Mansour and Al-Ajmi, 2020). Very soon SC disruptions spread from China across the globe and to different activities (Huang, Wang, Li, Ren, Zhao, Hu, Zhang, Fan, Xu, Gu, & Cheng, 2020; Zhu, Zhang, Wang, Li, Yang, Song, Zhao, Huang, Shi, Lu, & Niu, 2020) including the food supply system which, despite its fragility, drew many researchers' attention to this system's dynamics (Ozanne and Stolze (2021), product hoarding cases in anticipation of food shortages (Hall, Prayag, Fieger & Dyason, 2020; Venuto, 2020), increasing online purchasing/delivery options (Dunkley, 2020; Smith, 2020) and so on.

Unemployment levels rose worldwide as a direct result of lockdown restrictions on retailers/shopkeepers affecting supply and demand (Singh, Kumar, Panchal & Tiwari, 2021) and leaving many consumers in the brink of starvation (Charles, 2020), hence demonstrating how lockdown measures could not be considered a permanent solution to be adopted by government officials from an economic and social standpoint (Block, Hoffman, Raabe, Dowd, Rahal, Kashyap & Mills, 2020).

Eventually, the International Labour Organization (ILO) stated that all businesses “are facing serious challenges, especially those in the aviation, tourism and hospitality industries, with a real threat of significant declines in revenue, insolvencies and job losses in specific sectors” (ILO, 2020, p. 2), with Small and Medium Enterprises (SME) suffering most. At the same time, the International Monetary Fund (IMF) has regarded the impact of COVID-19 pandemic on the world economy “the worst recession since the Great Depression” (IMF, 2020).

Nikookar and Yanadori (2022) have demonstrated how the COVID-19 pandemic once again showed the importance of building SC robustness and resilience. The authors’ study goes even further by highlighting the critical role SC managers' social capital, human capital and cognition play in the development of three organizational supply chain resilience antecedents (visibility, responsiveness and flexibility) which subsequently increase a firm's supply chain resilience. In other words, policy makers should organize cross-functional teams able to create contingency plans, help the organization leaders to monitor human resources, finances, inventory levels, marketing and sales activities, among other measures (Al-Mansour and Al-Ajmi, 2020). In the US, FEMA’s Supply Chain Task Force has been working with all major commercial distributors to implement a strategy able to maximize the availability of lifesaving resources aiming for a nationwide COVID-19 response (FEMA, 2020).

2.3 PORTS

The Britannica Dictionary (2022) defines “port” as “a town or city where ships stop to load and unload cargo; a place where ships can find shelter from a storm”. Adopting a SC standpoint, Haralambides (2002) considers a port an interface between land and sea, a node in a transport chain, or a place where goods transfer between different modes of transport and, therefore, a port's core business is cargo-handling. Nevertheless, it should be noted it is not limited to moving cargo on and off ships: in recent years, logistics service provision in an international context has also been provided in various seaports (Wang and Cullinane, 2006); after all, reliability and predictability are basic requirements in a world of just-in-time time production processes (Munim & Schramm, 2018).

Ports can have different infrastructure and offer a wide range of services, depending on ship size (i.e., Panamax, Post-Panamax, Capesize) type of cargo handled (i.e., coil, solid bulk, container) and so on (Yieldstreet, 2019). Some of the main service categories include maritime services (i.e., pilotage, vessel traffic management and chandlering), terminal services (i.e., container handling and transfers, bagging and packaging and cargo storage), repair services (i.e., container and chassis repairs, dry dock ship repairs and dredging and maintaining channels and basins) and Information and Communication Technology (ICT) services (i.e., cargo track and trace, notification of ship arrival and data exchange for efficient cargo handling), among others (World Bank, 2003a; Langen, 2015 *apud* Weschenfelder, 2015).

Source: adapted from Weschenfelder (2015)

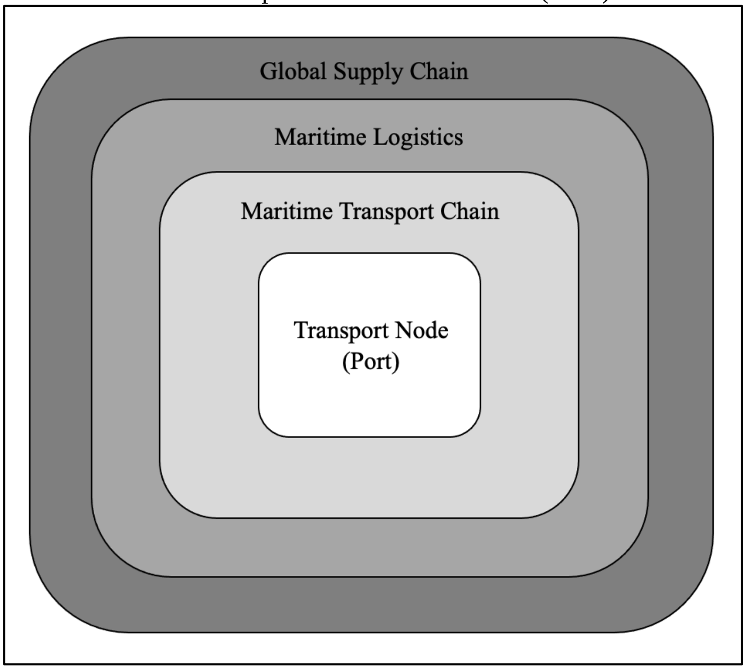

Figure 1: Global SC layers

More recently, seaports have drawn attention to their logistical function in the sense that, more than just cargo handling, ports represent decisive nodes in value-driven supply chains (Notteboom, Pallis & Rodrigue, 2022). Comprehensively, Zhang, Qu and Dai (2021) point out the following:

> "Modern ports from the perspective of the supply chain should rely on good ownership (hardware and software facilities) to obtain the best control capabilities and rely on ownership and control capabilities (internal and external resources) to obtain the best service capabilities (customer service level) and the strongest innovation capabilities (competitiveness and adaptability)." (p. 1)

The World Bank's Port Reform Toolkit (2003) outlines the four basic port management models according to different arrangements of public/private roles across various port activities, as follows: Public Service Port, Tool Port, Landlord Port and Private Service Port. Ferrari, Parola and Tei (2015) further state that the degree of public/private involvement in port management operations is what basically differentiates one model from the other, dictating the terms of risk sharing between concessionaires and port authorities during terminal concession contracts (Cruz and Marques, 2012). It is also worth mentioning that there is private sector presence in port infrastructure only in Landlord and Fully Privatized models (Weschenfelder, 2015).

Port competitiveness is one of the most complex yet important components of a successful transport system. In general, high levels of competitiveness in the international market suggest a port is able to provide quality services and, ultimately, high throughput volumes (Liebuvienė and Cˇižiu¯nienė, 2022). Nemuraite˙ (2011) includes other levels of competition besides the international one: between regions, between individual ports, internal port competition between individual terminals and, finally, competition between modes of transport.

Seaport competitiveness assessment involves the following aspects: port depth, port development, creating and improving the image of ports, increasing port capacity and maximizing port security and reliability (Noritake and Kimura, 1983; Puidokas and Andriuškiene˙, 2012; Sölvell, 2015; Sölvell, 2015a). Furthermore, the influence of external (i.e., global/national context) and internal (i.e., human, institutional, physical-technological and economic) factors is also considered; the former undergoing Political, Economic, Social and Technological (PEST) analysis and the latter ones being examined through the lenses of the theory of inputs and outputs (Liebuvienė and Cˇižiu¯nienė, 2022). Take the US, for example: with low estimates for container trade growth, port congestions and shifting trading lanes forcing changes in the country's port industry over the last few years, all three levels of government (federal, state and local) responded by adopting actions like greater agency engagement, infrastructure investments and strategic collaborations in order to increase ports' market power (METRANS, 2016).

Historically lacking an adequate public policy and incentives towards progress, Brazil's federal government has passed legislation clearing the way for the restructuring of its maritime sector hoping to free ports from State monopoly and enhance ports efficiency in recent decades. In 1993 the Brazilian Ports' Modernization Law was introduced as a cornerstone for general regulation and expansion processes. Despite eventually not fulfilling expectations it was certainly a prerequisite for Brazil's maritime trade development, allowing for a growing participation of the country's ports and terminals in foreign commerce through the encouragement of private sector participation, better labor conditions, costs reduction, agile operating processes, cabotage and inland navigation stimulus and so on (Oliveira, 1992).

A new regulatory mark would then be introduced in 2013 (originally a 2012 Provisional Presidential Decree) with the purpose of amending legal issues around public goods concessions, power rebalancing among entities involved, changing criteria for judging bids, establishing deadlines and service levels, etc. (Farranha, Frezza & Barbosa, 2015).

Additional initiatives have been implemented during the ongoing federal administration. Due to a 2018 truck drivers' strike which raised awareness about Brazil's logistical system being highly dependent of road shipments, a bill was introduced to Congress a year later to establish a cabotage navigation incentive program. Commonly known as "BR do Mar", it fosters legal and tax incentives, permits foreign ship freight and authorizes the existence of Brazilian shipping companies that technically do not own a fleet, contributing with decreasing transportation costs and consequently increasing the country's maritime industrial competitiveness.

Also, in an effort to encourage permanent search for excellence in public by port authorities, the "Portos+ Brasil" award was created by the Ministry of Infrastructure as a way to evaluate the port sector and acknowledge good governance, management and transparency practices. It is noteworthy that, combined with a more pro-market approach, such practices contributed to turn a port sector loss of around 1 billion reais in 2018 to an approximately 350 million reais profit in the following year. Finally, for its role as Brazilian Maritime Authority, the Brazilian Navy has been responsible for implementing the "e-Navigation" project, consisting of a wide range of integrated systems and services related to maritime and port services; these will help optimize information exchange, maritime situational awareness and the decision-making processes of port authorities and other related entities (Mattos, 2021; Brasil, 2022; Brasil, 2022a).

2.3.1 Container Ports

For centuries, ever since mankind's travel and commercial activities began covering long distances by sea the transport of goods has matured mostly driven by creative efforts in order to improve cargo loading and transportation activities. The process of loading and unloading of goods evolved from the ancient Greeks and Romans' manual handling of sacks, crates and barrels through a very labor-intensive process to a much more mechanical onboard hauling of boxed cargo. The lack of storage space utilization inside ships due to different size packages gave way to a more optimal cargo arrangement as a direct result of the adoption of standardized container units so-called "Twenty-foot Equivalent Unit" (TEU) and "Forty-foot Equivalent Unit" (FEU) (Flexport, 2022; Flexport, 2022a).

And what was once a risky method of covering goods sensible to damage and theft due to exposure became a very safe and protected mode of packaging and transport. Indeed, there was a great need for a standardized method of transport, especially during the second Industrial Revolution (1900s) but it wasn't until the 1950s that transport entrepreneur Malcolm McLean's idea of containerization was brought to light. Partnering with engineer Keith Tantlinger, McLean was finally able to conceive a standardized form of shipping container (Discover Containers, 2021; The Maritime Executive, 2021). And so, "by developing the first safe, reliable, and cost-effective approach to transporting containerized cargo, McLean made a contribution to maritime trade so phenomenal that he has been compared to the father of the steam engine, Robert Fulton." (Mayo and Nohria, 2005, p. 1).

The phenomenon of containerization brought along standardized procedures and economies of scale that ultimately reshaped the world economy and propelled the international intermodal transportation business, a basic requirement for modern global SC. As highlighted by Levinson (2016), "sleepy harbors such as Busan and Seattle moved into the front ranks of the world's ports, and massive new ports were built in places like Felixstowe, in England, and Tanjung Pelepas, in Malaysia, where none had been before" (p. 2). Not only that, lower operational and labor costs meant maritime transport business itself could envision better multimodality possibilities, forcing a mindset change among shippers and port authorities from a "door-to-door" to a "port-to-port" concept (Frémont, 2009; iContainers, 2019; Weschenfelder, 2015).

The numbers are impressive: it is currently estimated that over 34 million containers carry roughly 60 per cent of the world's goods transported by sea (around US$ 14 trillion) per year, with the global deadweight tonnage of container ships and total volume of freight having jumped from 11 to 275 million metric tons and from 0.1 to 1.85 billion metric tons respectively between 1980 and 2020 (MoverDB, 2022; OECD, 2022; Statista, 2022).

Southeast Asia stands out as the busiest region of the world in total container cargo trade with roughly two-thirds of the top fifty and nine out of the top ten busiest container ports being based there (MoverDB, 2022; World Shipping Council, 2020); the Port of Shanghai, together with five other Chinese container ports, has topped the list of ten busiest container ports in the world since 2010. In fact, China alone has been a key player in the sector, having been responsible for 40 per cent of the overall TEU total in 2020 despite undergoing a trade war along with the US while having been the epicenter of the COVID-19 outbreak (Lloyd's List, 2020). This should come as no surprise since the offshoring of manufacturing operations to

Asia (mainly China) over the last decades has propelled the global container trade (Fransoo and Lee, 2013).

In today's maritime transport segment shipowners' monopolies have been a growing feature. Having benefited from the high prices in recent years predominantly due to COVID-19 and geopolitical tensions (Brexit, US and China trade conflict and war between Russia and Ukraine), large ocean freight carriers are now investing their income surplus in setting up their own container terminals, freight forwarding and other modes of transport such as air freight while increasing the size of vessels to enjoy economies of scale; all this eventually adds stimulus for port structures around the globe to adapt to a new maritime market reality (Lindert, 2022; Brasil, 2022b).

Container transport's role in global SC has grown to such extent that scholars have called for more research on the matter, especially with regards to the ocean container transport's impact on SC performance and SC decision making (Fransoo and Lee, 2013). The same authors bring up recent trends in ocean container transport industry that deserve additional consideration: hub-and-spoke network development, economies of scale and energy prices, the increase in intermediate products being shipped due to manufacturing outsourcing and offshoring and so on. Moreover, four research lines regarding container SC are also proposed: the coordination of container shipments, pricing and risk management, competition between ports, carriers, and container terminals, and capacity management. (Fransoo and Lee, 2013).

Other researchers in the field of ocean container transport have also sparked debate. For instance, container imbalance (given the asymmetric nature of global trade) and the resulting empty container repositioning issue have been dealt with in Francesco, Lai and Zuddas (2013), Xie, Liang, Ma and Yan (2017), Wang, Wang, Zhen and Qu (2017) and so on. Dang and Chu (2016) are among those who have supported the sustainable container management as reusable packaging. Muñuzuri, Onieva, Escudero and Cortés (2016) have followed others in investigating the impacts of a tracking-and-tracing system for containers, while Hu (2011) have argued in favor of a container multimodal transportation scheduling for emergency situations.

Finally, in Lee and Song (2017), a careful literature review is conducted around strategic planning (competition and cooperation, and pricing and contracting), tactical planning (network design and routing, and ship scheduling and slow steaming) and operational management issues (empty container repositioning, and safety and disruption management). Regarding the latter dimension, the authors indicate the need for more research on disruption management in container shipping (i. e., Brouer, Dirksen, Pisinger, Plum & Vaaben, 2013; Clausen, Larsen, Larsen & Rezanova, 2010; Li, Qi & Lee, 2015; Yu & Qi, 2004), with particular focus on those kinds of disruption that are not caused by regular uncertainties but rather a result of occasional events such as port closures due to natural phenomenons (i.e., high winds, hurricanes or floodings), port congestion due to labor strikes, terminal unavailability due to quay crane failures and so on.

2.4 PORT CONGESTION

Being important focal points in the global trade network, seaports can unfortunately also represent major SC bottlenecks in some cases. One of many SC disruption outcomes as mentioned above, port congestion is a scenario where long delays, queuing and dwell time of cargo and ships at a port often translate into loss of trade and extra costs, (Nze & Onyemechi, 2018). Following the onset of the pandemic port congestion has caused frictions in global trade and transport system as the approximately 25 per cent increase in shipping times combined with labor shortages and the need for infrastructure upgrading resulted in rising prices and even empty supermarket shelves in major economies (IMF, 2022).

Take the US, for example: household savings increase rising up from an average of 8 per cent in 2019 to as high as 34 per cent in April 2020 plus government stimulus packages due to lockdown measures eventually increased demand for goods and online services (Carter, Steinbach & Zhuang, 2021); this led to a 17.5 per cent surplus in incoming shipping containers, the majority of those bringing imports from Asia (Steinbach, 2022), which caused an empty container surge that generated extraordinary measures to ease congestion and send those metal boxes back to China and other neighboring exporting countries (Lopez, 2021). Such imbalance ultimately created considerable shipping fee differences between import and export destinations: “in September 2021, the fee for shipping a single 40-foot container (FEU) from Shanghai to Los Angeles was $12,000 versus only $1,400 for the backhaul from Los Angeles to Shanghai” (Carter *et al.*, 2021, p. 2).

In the fullness of time, port congestion represents a test of a port’s resilience, understood here as how Linkov and Palma-Oliviera (2017) define it: “the ability of the system to withstand a change or a disruptive event by reducing the initial negative impacts (absorptive capability), by adapting itself to them (adaptive capability) and by recovering from them (restorative capability)” (p. 191). The first one means a port’s ability to maintain service levels while absorbing a disruption through operational redundancies, visibility and transparency. The second shows how ports anticipate or react to a disruption like a congestion by adjusting operations (i.e., schedules, workforce, terminals) or even changing management (while communicating stakeholders). And the latter constitutes the way a port restores or even surpasses previous service levels after responding to a disruptive event via its preparedness, recovering lost capacity and/or simply understanding a certain disruption as a “learning event” (Notteboom, Pallis, & Rodrigue, 2022).

Blanchard (2007) offers additional reactive/proactive solutions that can come at a good time to mitigate port congestion effects such as cargo redistribution, transportation demand planning, virtual warehousing (or inventory-in-motion), change of port of call and favorable legislation lobby, to name a few. From a different perspective, Gui, Wang and Yu (2022) demonstrate that port congestion also brings long-term economic effects (i.e., reduced income, declined competitiveness, increased risk of debt and bankruptcy); hence the importance of risk assessment in port congestion management, especially during COVID-19 since it has rapidly affected the maritime SC bringing unprecedented chaos to ports worldwide and virtually the entire shipping industry (Gui *et al.*, 2022).

2.5 PORT PERFORMANCE

Avoiding or at least mitigating such disruptive events in maritime SC requires ports to efficiently run its operations. However, ports alone cannot perform properly without healthy local economical environments. That is why maritime nations have directed resources not only to port infrastructure (i.e., number of berths, terminal length, cargo throughput) but, in some cases, even to the progress of their surrounding areas for the purpose of creating an interactive evolution of port infrastructure and port city economy that favors trade and regional economy development (Liu, 2020). This is in line with Notteboom *et al.* (2022) argument that efforts to establish mutual links between ports and cities have produced the revival of older abandoned port areas (aka. waterfront redevelopment) through the creation of multifunctional areas with plenty of employment opportunities (housing, sports, recreation, tourism), cultural sights (i.e., Guggenheim Museum in Bilbao, Elbphilharmonie in Hamburg) and even cruise industry destinations (i.e., Rotterdam, Antwerp).

Zhang et al. (2021) add that a port’s development is guided by four main capability factors: a port’s resource ownership, innovation-driven capabilities, control and management capabilities, and comprehensive service capabilities. This is particularly a challenge for developing countries (i.e., Brazil, Mexico, Nigeria) where poor financial, managerial and technological resources are rule of thumb. That is why most developing countries conducted port sector reforms in order to promote the necessary management and funding philosophy required to reposition seaports in the face of new challenges (Onwuegbuchunam, 2018). All major types of combination between port/terminal ownership and operations that constitute the four port management models have been mentioned above (please refer to section 2.7 – Ports). A port managers' job is, thus, to select the one that at the end of the day boosts market share, competitive advantage and the port's performance and effectiveness (Onwuegbuchunam, 2018).

Different from port efficiency (to be further explained), port performance is the way port authorities and managers compare a port's outcomes with competitors to know if they are performing up to the prevailing standards or needing operational or infrastructure improvements and is commonly measured by port performance indicators (PPI) (UNCTAD, 2016). Wiegmans and Dekker (2016) add that companies, port terminal operators and port authorities make use of various performance management techniques to measure cost-effectiveness, profitability and quality of their operations. Some of the first PPI on record came about in the UNCTAD's famous 1976 monograph in which a set of financial performance indicators (i.e., tonnage worked, berth occupancy revenue per ton of cargo, capital equipment expenditure per ton of cargo) and operational performance indicators (i.e., waiting time, turn-round time, tonnage per ship) were formally introduced (UNCTAD, 1976).

Ever since then much has been done to update those PPI, not only because of modern day innovations and technical requirements but mostly because earliest ones focused on terminal productivity rather than *port* productivity (de Langen, Nijdam & Horts, 2007), a more embracing, and suitable, concept since, in reality, a port functions as a cluster of numerous economic activities (de Langen, 2004).

Most recently, UNCTAD's Train for Trade initiative (2012) has led efforts alongside partner institutions such as the renowned maritime statistics data provider Marine Traffic to develop a Port Performance Scorecard to serve as benchmarking throughout the maritime industry. Inspired by Kaplan and Norton's Balanced Scorecard, where strategy is put at the core of a company's performance aspirations (Kaplan & Norton, 1992) and based on four strategic dimensions (finance, operations, human resources and market) to reflect a modern port's dynamics, the objective of this Scorecard is to investigate the generic measures that should be adopted/developed by all port authorities in order to facilitate comparison of ports both in nationally and internationally dimensions (UNCTAD, 2016, p. 11).

Similar initiatives have also been brought by the World Bank since early 1990s such as the 2016 performance report of container ports in South Asia, the Logistics Performance Index (LPI), the Port Reform Toolkit (aiming at port governance and reform), several other reports on latest maritime trends (i.e., maritime networks, hinterland connectivity and port efficiency) and, lately, the launch of the Container Port Performance Index (CPPI), developed in co-operation with ICT solutions company IHS Markit (Notteboom, Pallis, & Rodrigue, 2022a).

Grounded on total port hours per ship call, since 2021 the CPPI serves as reference point for stakeholders (i.e., national governments, port authorities, private operators of trade, logistics and supply chain services) to identify opportunities for container port infrastructure, operation and management improvements (World Bank, 2021). As reported by the latest CPPI report (World Bank, 2022), Saudi Arabia's King Abdullah Port tops the list while Colombia's Cartagena leads the Latin America region at 12th place and Imbituba comes as the best performance of a Brazilian container port in 51st position.

2.6 PORT EFFICIENCY

Container terminal and deep-sea container port performance studies in terms of efficiency are a relatively new subject compared to other public services (i.e., agriculture, health, banking) but have been widely studied in recent years (González & Trujillo, 2009; Rezaei, Palthe, Tavasszy, Wiegmans & Laan, 2019). Depending on research approach, port efficiency can be translated into reliability and speed of port services (Tongzon, 2009), quality measurement of resources expenditure (Kim and Marlow, 2001) or it can symbolize a minimizer or maximizer concept (Organisation for Economic Co-operation and Development - OECD, 2002), when the aim of a research is usually an evaluation of port/terminal efforts in transforming inputs (minimizing concept) into outputs (maximizing concept).

Although efficiency may well be confused with productivity since a firm's performance increases as it becomes more productive and efficient, productivity translates to an input/output ratio whereas efficiency means comparing a firm's values of outputs and inputs to its competitors' optimum relative input/output values (González and Trujillo, 2009). In fact, this is the main rationale supporting port efficiency as this research's theme. Another argument backing this choice is the fact that increasing efficiency means performance improvement towards an optimum level (Suárez-Alemán, Serebrisky & Ponce de León, 2018).

Oliveira and Cariou (2015) reveal that scholars have sought to explain efficiency by applying multiple techniques/methodologies while taking into consideration technical or scale efficiencies, a port's institutional environment (degree of private versus public ownership) and macro-economic factors (e.g., gross domestic product - GDP, port-city population and hinterland connections). Specialization, port size and competitiveness have also been considered as (in)efficiency drivers (Chang & Tovar, 2014; Oliveira & Cariou, 2015; Pérez, González & Trujillo, 2020; Tongzon & Heng, 2005).

Table 1: Main benchmarking techniques/methodologies

Classification of literature	Technique/ Methodology	Disadvantages
Economic Impact Studies - Port Economic Impact - Port Trade Efficiency	I-O tables, mass-calculation, CGE models, etc. Cost/production function, gravity models	Analyse ports either as regions or as trade /transport components rather than business or operating units
Index Methods - Financial ratios - Snapshot indicators - SFP - PFP/MFP - TFP	Financial ratios: NPV, IRR, Gearing ratio, etc. Snapshot indicators: Throughput in TEU, total turn-around time, service time, cargo dwell time, etc. SFP: Single output/single input PFP: Subset of outputs/subset of inputs TFP: - The Törnqvist & Fisher (superlative) indexes - The Malmquist index: Does not require functional form, and can be decomposed into different sources of efficiency	Financial ratios: Little correlation with the efficient use of resources, focus on short- term profitability, dissimilarity between various port costing and accounting systems, problems with price regulation and access to private equity Snapshot indicators: Provide an activity measure rather than a performance measure. SFP/PFP: Provide average productivity but does not capture overall productivity. Non-statistical approach TFP: Requires estimation of cost, production or distance function (otherwise unable to separate scale effects from efficiency differences). Non-statistical approach
Frontier analysis - Deterministic versus stochastic - Parametric versus non-parametric	- COLS: deterministic /parametric - DEA/FDH: deterministic /non-parametric. - SFA: stochastic/parametric	COLS: Requires functional form and dominated by the position of the frontier firm SFA: Requires functional form, specification of exact error terms and probability of their distribution DEA: Sensitivity to choice of weights attached to input and output variables. No allowance for stochastic factors and measurement errors
Process approaches - Bottom-up approaches - Benchmarking toolkits - Expert judgement - Perception surveys	- Engineering economic analysis (EEA) - Enterprise modelling (ERP) - Process benchmarking (BSC, TQM) - Business process modelling (BPR) - Action research, focus groups, etc. - Statistical techniques for survey inquiry and hypothesis testing	EEA: Data intensive, relies on expert judgement and knowledge of the system BPR/ERP: Expensive to build and maintain Process benchmarking: Process approach, does not capture operational efficiency component & trends

Source: Bichou (2009)

From the time Farrell (1957) proposed the idea of measuring the performance of different production units against an estimated efficient frontier onwards, numerous research lines have emerged in the field of efficiency analysis. In line with Chang and Tovar (2014), port efficiency literature specifically using frontier analysis models has built up significantly since the first empirical studies in the 1990s. The same authors identify two main categories under which studies in the field can be grouped: parametric techniques (Aigner, Lovell & Schmidt, 1977; Meeusen & Van der Broeck, 1977), mostly represented by Stochastic Frontier Analysis (SFA), and non-parametric ones, the key example being Data Envelopment Analysis (DEA), introduced by Charnes, Cooper and Rhodes (1978).

Each approach has its own set of advantages/disadvantages. On one hand, econometry's Stochastic Frontier Analysis (SFA) is stochastic and parametric and, therefore, is able to distinguish noise effects from inefficiency ones even though it may regard an improper functional specification as inefficiency. On the other hand, linear programming's DEA is non-stochastic and non-parametric; hence, it does not require functional specification despite dealing with both noise and inefficiency together (Chang and Tovar, 2014; Gonzalez and Trujillo, 2009; Lovell, 1993).

3 METHODOLOGY

This section generally describes DEA, outlines the research approach in terms of philosophical worldview and design while justifying the use of two-stage network DEA together with Malmquist index, informs the temporal/spatial delimitation of data collection/analysis and how they will be collected, and defines which inputs, intermediate input/output and output will be surveyed.

3.1 DATA ENVELOPMENT ANALYSIS (DEA)

Efficiency measurement requires a benchmark, which, as stated by Bhutta and Huq (1999), "is first and foremost a tool for improvement, achieved through comparison with other organizations recognized as the best within the area" (p. 255). Regarding managerial practices, benchmarking has been described as a "continuous, systematic process for evaluating the products, services, and work processes of organizations that are recognized as representing best practices, for the purpose of organizational improvement" (Talluri and Sarkis, 2001, p. 211).

Being an extreme point method comparing each unit of production with only those deemed the "best ones", DEA is highly regarded as an efficiency benchmarking technique (Wiegmans & Dekker, 2016). Moreover, as ports have become important nodes in maritime SC, DEA presents itself as a standardized, robust and transparent methodology capable of quantitatively and qualitatively measure relative operational performance, identify operational gaps and opportunities, assess operational progress over time among other features that justify its application in SC performance measurement (Wong & Wong, 2008). It is also worth mentioning there are no assumptions regarding the basic functional form relating independent and dependent variables in DEA (Charnes, Cooper, Lewin & Seifort, 1994).

As previously mentioned, DEA is a methodology that employs a linear programming approach based on input and output variables in order to measure the efficiency of decision-making units (DMUs). Wong and Wong (2008) consider a DMU to be an economic agent with limited resources eager to reach specified performance goals with as few inputs as possible. Efficiency measurement in DEA revolves around the fundamental concept of "efficient frontier" rather than central tendencies; hence, "instead of trying to fit a regression plane through the center of the data as in statistical regression, for example, one 'floats' a piecewise linear surface to rest on top of the observations" (Cooper, Seiford & Zhu, 2011, p. 2).

There are two set of events under which DEA is mainly applied: it can either be used to compare performance between firms (assuming all firms have similar strategic goals and directions), or it can be employed in a longitudinal analysis by comparing the efficiency of a department or firm over time (Metters, Frei & Vargas, 1999).

The original CCR model proposed by Charnes, Cooper and Rhodes in 1978 was meant to be applied to technologies exhibiting constant returns of scale. Six years later, Banker, Charnes and Cooper (1984) incremented the previous model by conceptualizing a new one (BCC model) able to make room for operations characterized by variable returns of scale. And thereupon numerous researchers developed different models based on the CCR-BCC models, mainly differing in terms of their orientation (input-orientation, output-orientation), diversification and returns to scale (CRS – constant return to scale, VRS – variable return to scale, NIRS – non-increasing return to scale, NDRS – non-decreasing return to scale), disposability (strong, week) and types of measure (radial measure, non-radial measure, hyperbolic measure) (Wong & Wong, 2008).

Nevertheless, DEA has its own limitations. Statistical noise forbiddance is regarded as the most serious one: measurement errors, presence of outliers and absence/exclusion of inputs/outputs are some examples of what may influence results (the latter being particularly difficult to avoid as companies are occasionally unwilling to share some data deemed confidential). Also, there should be an ideal upper limit to the ratio of inputs/outputs compared to DMUs since it tends to increase the number of efficient DMUs.

Moreover, it is not recommended to apply DEA when comparing DMUs belonging to different SC tiers since, ideally, they should have similar strategic goals and objectives. Finally, standard DEA methods do not account for environmental differences, meaning the inefficiencies are revealed but what caused them in the first place are not; therefore, companies should consider this specific limitation whenever managerial competence is under scrutiny. (Ray, 2002; Rickards, 2003; Wiegmans & Dekker, 2016; Wong & Wong, 2008).

Despite still being subject to criticisms when applied for multi-port evaluation performance analysis (Bichou, 2011; Panayides, Maxoulis, Wang & Ng, 2009; Talley, 2007), numerous studies on port efficiency have made use of DEA, with Roll and Hayuth (1993) being regarded as the first ones to have applied such methodology even though they had not analyzed any empirical data in that occasion.

Liu (1995) applied translog function to a sample of 28 United Kingdom ports (1983–1990) to demonstrate that public terminals efficiency is lower than private ones. Martinez-Budria, Diaz-Armas, Navarro-Ibanez and Ravelo-Mesa (1999) applied the DEA-BCC model to a sample of 26 Spanish ports (1993–1997) in order to quantify their relative efficiency and conclude that efficiency is positively correlated to complexity. Valentine and Gray (2001) applied a DEA-CCR model to 31 container ports (1998) to show how organizational and administrative structure impact efficiency. Barros and Athanassiou (2004) chose two Greek and four Portuguese ports (1998– 2000) to apply DEA-CCR and DEA-BCC models and find that inefficiency is mainly a result from scale, while Cullinane, Wang, Song and Ji (2006) exposed port performance evolution by also applying both DEA-BCC and DEA-CCR models to the world's leading container ports ranked among the top 30 in 2001.

In following years regression techniques and bootstrapping methods have been applied in DEA studies in order to observe how certain factors influence port efficiency (Andrade, Lee, Lee, Kwon & Chung, 2019). Drawing upon Simar and Wilson's (2007) bootstrapping method, Barros and Managi (2008) analyze DEA scores obtained for 39 Japanese seaports (2003–2005) to identify efficiency drivers. In an effort to calculate efficiency scores for Chinese ports, Yuen, Zhang and Cheung (2013) applied DEA-CCR and DEA-BCC models together with Tobit regression to investigate the impact of ownership structure and port competition on port performance. They discovered that government ownership and intra/inter port competition enhanced the efficiency of Chinese ports. Wan, Yuen and Zhang (2014) applied a two-stage DEA and Tobit regression method to measure US container port productivity by analyzing the impact of hinterland accessibility, represented by rail facility and road congestion.

Among current new trends in DEA application on port efficiency are DEA metafrontier analysis (Medal-Bartual, Molinos-Senate & Sala-Garrido, 2017), uncertainty DEA (UDEA) (Pham, Park & Choi, 2021), inversed DEA (IDEA) (Lin, Yang & Wang, 2019), use of fuzzy approaches associated with two-staged DEA (Castellano, Fiore, Musella, Francesca, Punzo, Risitano, Sorrentino & Zanetti, 2019) and even three-stage DEA (Huang, Wang, Dai, Luo & Chen, 2020) with a focus on contemporary issues such as efficiency of waste generation in port terminals and other environmental policies improvements (Garcia, Silva & Freitas, 2017; Sun, Yuan, Yang, Ji & Wu, 2017).

With regards to studies on Brazilian ports efficiency using DEA, Rios and Maçada (2006) raised awareness about the absence of DEA Brazilian port efficiency studies. Years later, Wanke *et al.* (2011) likely inaugurated studies on Brazilian seaport performance by applying DEA and SFA models to 25 terminals. They discovered that, even though most terminals exhibited low capacity due to the country's export boom and lack of investments in capacity expansion, increasing returns to scale were identified and type of cargo handled played an important role in determining port performance. Barros, Felício and Fernandes (2012) applied a Malmquist index with technological bias to determine Brazilian ports productivity from 2004 to 2010.

Additional and more sophisticated techniques gradually began to be applied. Wanke (2013) used a two-stage network-DEA centralized efficiency model to investigate the physical infrastructure and shipment consolidation performance of Brazilian ports, highlighting positive impacts of private administration on physical infrastructure performance, and cargo diversity and hinterland on consolidation efficiency.

Rubem, Brandão, Costa, Angulo-Meza and Mello (2015) applied the Multiple Criteria Data Envelopment Analysis (MCDEA) to evaluate Brazilian container ports in 2013 and showed that their performance levels were homogeneous. However, not only the study was based on an insufficient number of DMUs, it lacked discrimination power; such issue could have been solved with Ghasemi, Ignatius and Emrouznejad's (2014) bi-objective weighted method (BiO-MCDEA), later applied by Andrade *et al*. (2019). Wanke and Barros (2016) employed DEA bootstrapping truncated regression technique to 27 major Brazilian ports with data covering 2007 to 2011, in order to find a strong positive impact of public-private partnerships (PPP) on port scale efficiency.

3.1.1 Two-stage Network DEA with Malmquist index

In the present postpositivist quantitative study (Creswell, 2018), CCR model Data Envelopment Analysis (DEA) is the methodology chosen to estimate the best practice frontier due to the heterogeneity of the sample and also since the advantages of applying this method outweigh its disadvantages: perform non-parametric calculations, capable of handling multiple outputs, does not require the development of a standard against which efficiency is benchmarked and, finally, the presence of DMUs that produce different outputs, making DEA a suitable technique for efficiency measurement (Wiegmans & Dekker, 2016). More pointedly, it follows the network-DEA two-step approach initially proposed by Liang et al. (2008) and Zhu's (2011), and later applied to Brazilian ports efficiency measurement by Wanke (2013) and Wanke and Barros (2016), to which readers should refer for additional information on the approach`s concepts.

In addition, a dynamic evaluation is incorporated to observe the efficiency evolution of the DMUs over a specific period of time. In the benchmarking literature the Malmquist index is regarded as the most popular approach to dynamic evaluations available since it aggregates the different inputs and outputs without taking into consideration the price factor. It basically demonstrates how much a firm or a unit of analysis has improved from one period to the next by considering technical and efficiency changes over time, the effects of which being multiplicative in the sense that the Malmquist index (M) is the product of the efficiency change

(EC) and the technical change (TC). Although it may not satisfy the so-called circular test and allow for the accumulation of the changes through several periods, the Malmquist measure is suitable for short periods of time (Bogetoft & Otto, 2011) such as in this study.

3.2 DATA AND VARIABLES SELECTION

The sample consists of Brazil's leading container terminals ranked in terms of annual container throughput. To that end, secondary data for a set of 20 Brazilian container terminals were gathered from port authorities' websites and federal government documents, reports and databases, including the statistical database provided by the National Water Transport Agency (ANTAQ) website (http://www.antaq.gov.br) delimiting four twelve-month periods (March/2018 to February/2019; March/2019 to February/2020; March/2020 to February/2021; March/2021 to February/2022). Such measure allows for a longitudinal analysis of the pre- and post- onset of the COVID-19 pandemic outbreak (WHO, 2020). These DMUs jointly represent roughly 95 per cent of Brazil's total container throughput. Readers should refer to Figure 2 in order to identify the terminals' geographic location and to figure 3 for a visual representation of the two-stage network DEA model herein applied.

In addition, this study employs an output-oriented model. Wong & Wong (2008) explain that, whereas in the input-oriented DEA analysis the "input is set equal to one and the model maximizes the sum of the weighted outputs", the output-oriented analysis "simply takes the reverse track where the model sets the output equals to one and minimizes the sum of the weighted inputs" (p. 41). Moreover, while input-oriented model concentrates on managerial and operational issues, output-oriented ones are normally associated with planning and strategy practices (Cullinane, Song and Wang, 2005) and better relate to this study's purposes.

Cullinane, Song, Ji and Wang (2004) offer a thorough discussion on variable definition that can be briefly summarized as follows: as accurately as possible, input and output variables should represent real objectives and existing processes of container port production, assuming a port's main objective is to minimize input(s) and maximize output(s). Since container port production depends crucially on the efficient use of land, labor and equipment, elements related to these resources should be incorporated into port efficiency models as input variables. On the other hand, container throughput is unquestionably the most widely adopted indicator of port or terminal output: almost all previous studies treat it as an output variable as it closely relates to the need for cargo-related facilities and services and for being the most appropriate and analytically tractable indicator of a port's production effectiveness (Cullinane *et al.*, 2006).

Source: adapted from IBGE (2022)

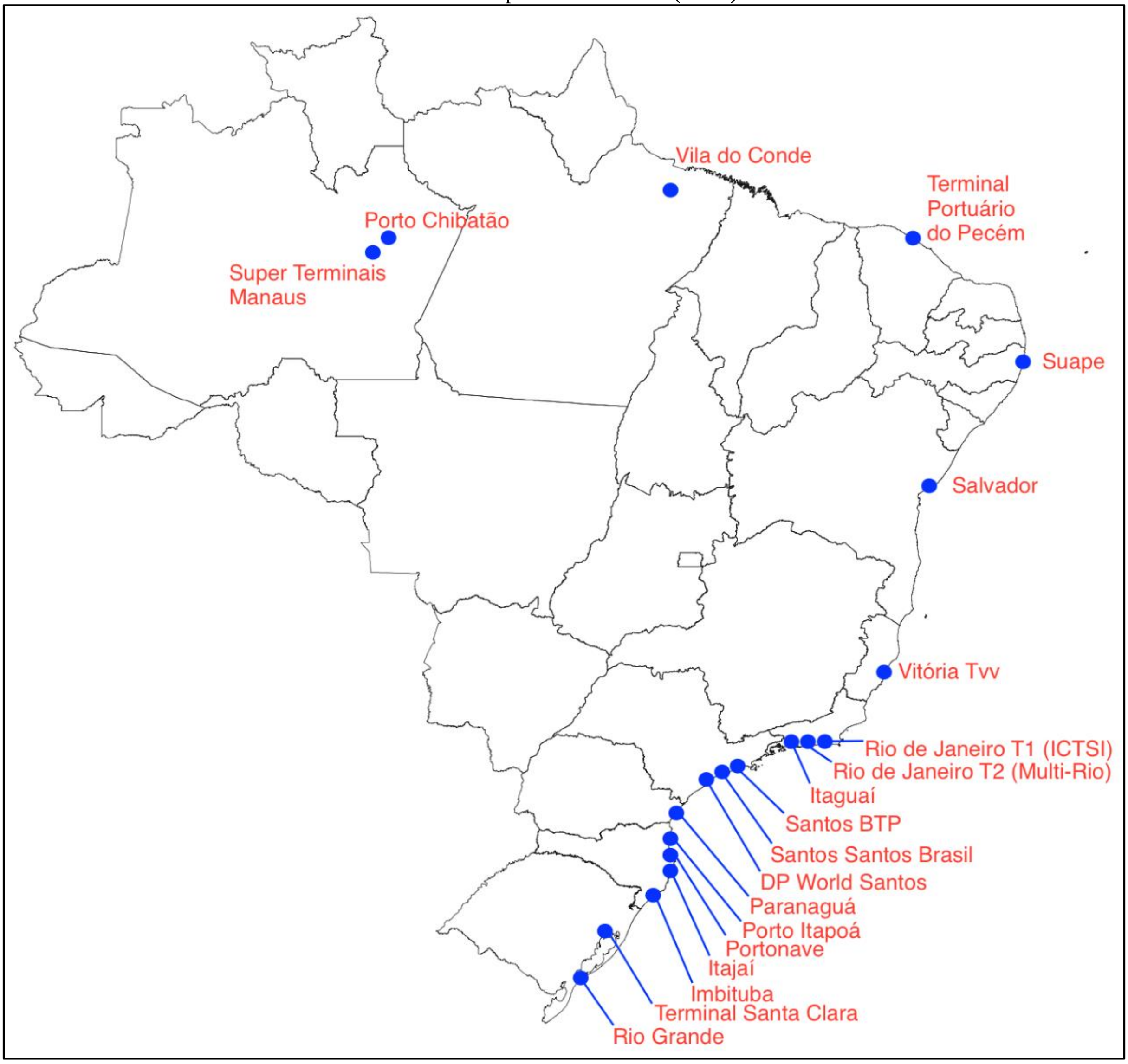

Figure 2: Geographical location of the 20 Brazilian container terminals

Source: adapted from Wanke (2013)

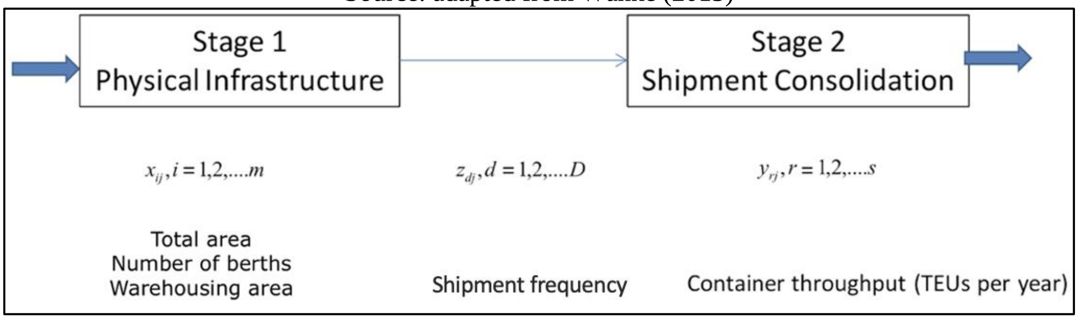

Figure 3: Two-stage network DEA model applied

In light of unavailability or unreliability of some data, the amount and selection of input/output variables was restricted to a total of five: total area, number of berths and warehousing area as input variables, shipment frequency as intermediate input/output and container throughput as output. It is worth to notice there is an ongoing debate over the minimum "DMUs to variables" ratio being 3:1 (i.e., Banker, Charnes, Cooper, Swarts & Thomas, 1989; Cooper, Seiford & Tone, 2007) or 2:1 (i.e., Golany and Roll, 1989; Lins, Meza & Antunes, 2000). Nevertheless, the total of DMUs that make up this study's sample satisfies both criteria. The selected variables derive support from the below mentioned literature:

Table 2: Compilation of Input, Intermediate Input/Output and Output Variables

Variables	Contents	Relevant Literature
Input	Total area	Wang and Cullinane (2006), Trujillo, González and Jiménez (2013), Yuen, Zhang and Cheung (2013)
	Number of berths	Rios and Maçada (2006), Liu (2008), Wanke (2013), Wanke and Barros (2016)
	Warehousing area	Wanke (2013), Wanke and Barros (2016)
Intermediate Input/Output	Shipment frequency	Wanke (2013), Wanke and Barros (2016)
Output	Container throughput	Valentine and Gray (2001), Wang and Cullinane (2006), Barros and Athanassiou (2004)

Source: elaborated by the author

Finally, a series of unstructured interviews were conducted with four container terminal officials and one port operations consultant for the sake of gathering complementary data that could contribute with general data interpretation.

4 RESULTS AND DISCUSSION

This section presents and discusses the empirical results derived from data analysis. They were obtained through a two-step process as follows: performing the two-stage network DEA on all four data sets of the four twelve-month periods, followed by applying a Malmquist-index approach in order to create the required longitudinal framework associated with an unpaired two-samples Wilcoxon test as a means to determine whether the efficiency differences revealed over time were indeed statistically relevant. Finally, mention should be made to the censReg package (Henningsen, 2012) where the pertinent calculations were conducted through customized R codes.

4.1 TWO-STAGE NETWORK DEA

Following below are findings obtained from performing the two-stage network DEA on all four data sets of the four twelve-month periods, mostly consisting of basic statistical sample traits of each period (table 3 below), relevant displays of terminal efficiency changes along with shipment frequency/container throughput commentaries and additional data.

Table 3: Two-stage network DEA basic statistical sample traits

Period	Statistics	Global Efficiency	Physical Infrastructure Efficiency	Shipment Consolidation Efficiency
MAR2018-FEB2019	Mean	0,03885	0,50909	0,09849
	Standard Deviation	0,05238	0,20306	0,16883
	Coefficient of Variation	1,34813	0,39886	1,71424
MAR2019-FEB2020	Mean	0,03845	0,52242	0,11387
	Standard Deviation	0,04571	0,24545	0,21551
	Coefficient of Variation	1,18890	0,46983	1,89255
MAR2020-FEB2021	Mean	0,03886	0,54696	0,09641
	Standard Deviation	0,05000	0,24654	0,14993
	Coefficient of Variation	1,28682	0,45075	1,55515
MAR2021-FEB2022	Mean	0,03864	0,57822	0,09905
	Standard Deviation	0,05126	0,26954	0,15854
	Coefficient of Variation	1,32646	0,46615	1,60063

Source: Elaborated by the author

4.1.1 March 2018 to February 2019

The first twelve-month period already reveals some common traits among all four periods: low overall global efficiencies (under 0,25), fairly distributed physical infrastructure levels despite relatively low shipment consolidation ones in general, very low number of terminals with at least 1 full efficiency level (none in this first period) and a relative predominance of 3 terminals (Terminal Santa Clara, Vila do Conde and Salvador) topping the global efficiency rank while Itaguaí and Porto Chibatão are listed as the lowest ones.

In addition, despite their relatively low global efficiencies, Paranagua (the fourth largest terminal) already emerges as the leading shipment frequency terminal throughout the four periods with third and fifth-largest Santos Santos Brasil and Santos Brasil Terminal Portuário (BTP) joining it in the top-five. These three terminals will also appear as some of the leading container throughput terminals. On the other hand, Super Terminais Manaus (fourth smallest) and Porto Chibatão (lowest global efficiency) occupy the lowest positions in shipment frequency while Imbituba and Terminal Santa Clara (the terminal with the smallest total and warehousing areas) come in the last positions.

4.1.2 March 2019 to February 2020

Despite a slight drop in its global efficiency the leading terminal (Terminal Santa Clara) appears as the only one with at least 1 full efficiency level (shipment consolidation). General minor rises/falls are also observed across all efficiency ranks as well as in the shipment frequency/container throughput ones. Regarding the latter ones, Dubai Ports (DP) World Santos stands out rising several positions in both ranks and starting an upwards trend throughout this time window as covered in more detail below. Total shipment frequency number increases by roughly 4% while total container throughput maintains an upwards tendency around 8,5%.

4.1.3 March 2020 to February 2021

During these first twelve months since the pandemic outbreak there was no terminal with at least 1 full efficiency level and, once again, general minor rises/falls are detected across all efficiency ranks. However, it is deserving of attention the virtually unchanged positions in the lower half of the shipment frequency/container throughput rankings along with reduced rises/falls in the upper one. This might indicate an overall tendency at the time to conduct inbound/outbound operations “as is” probably in order to avoid any additional complications. Moreover, total shipment frequency number suffers a minor contraction (approximately 1%) while total container throughput maintains an upwards tendency albeit around 4,5%.

4.1.4 March 2021 to February 2022

The last of the four twelve-month periods and one that could mark the beginning of worldwide SC recovery brings Santos BTP and Santos Santos Brasil, two of the largest terminals and the leading ones in container throughput, as the only DMUs with at least one full efficiency level (physical infrastructure). Additionally, total shipment frequency number is reduced by around 2% while total container throughput resumes a higher annual increment (this time at about 7,7%).

4.1.5 Two-stage Network DEA Special Cases

In short, almost all sample DMUs experienced minor global efficiency variances in each one of the four twelve-month periods. Nevertheless, some consolidated their relatively high/low ranking positions (Terminal Santa Clara, Vila do Conde and Salvador at the top; Itaguaí and Porto Chibatão at the bottom) while others moved up (DP World Santos) or down (Super Terminais Manaus) considerably.

4.1.6 Two-stage Network DEA Stages Representation

Both physical infrastructure and shipment consolidation efficiency levels calculated using the two-stage network DEA model for each of the 20 DMUs are given in the figures and table below.

Source: elaborated by the author

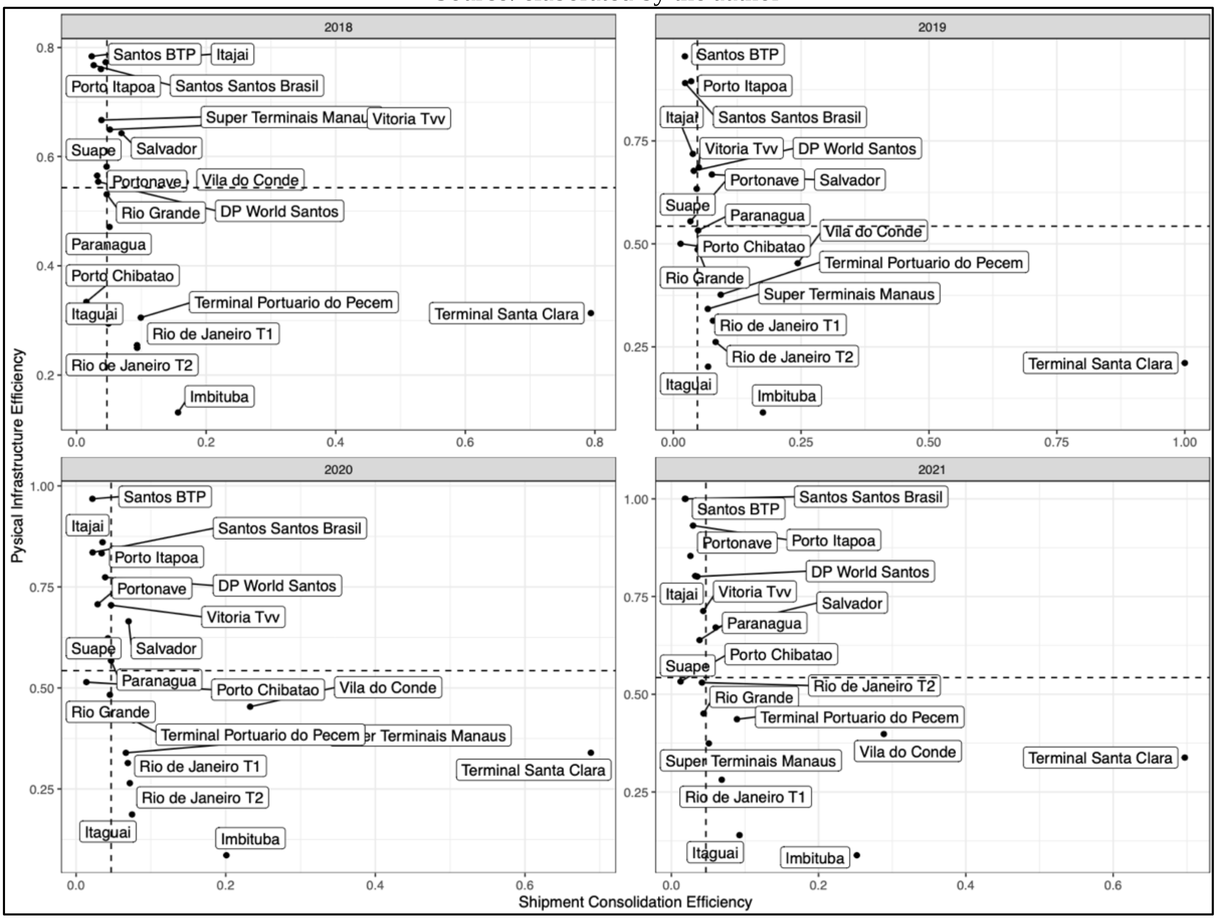

Figure 4: Physical infrastructure efficiency x shipment consolidation efficiency

Source: elaborated by the author

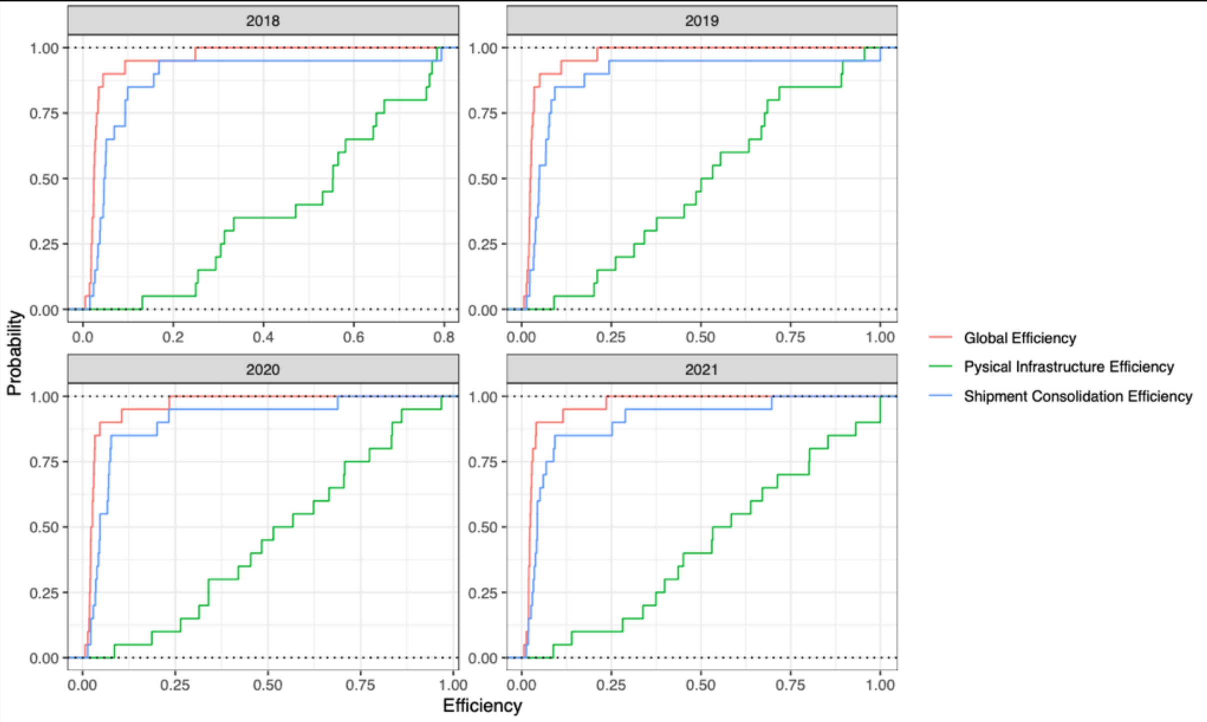

Figure 5: Probabilities scores

Source: elaborated by the author

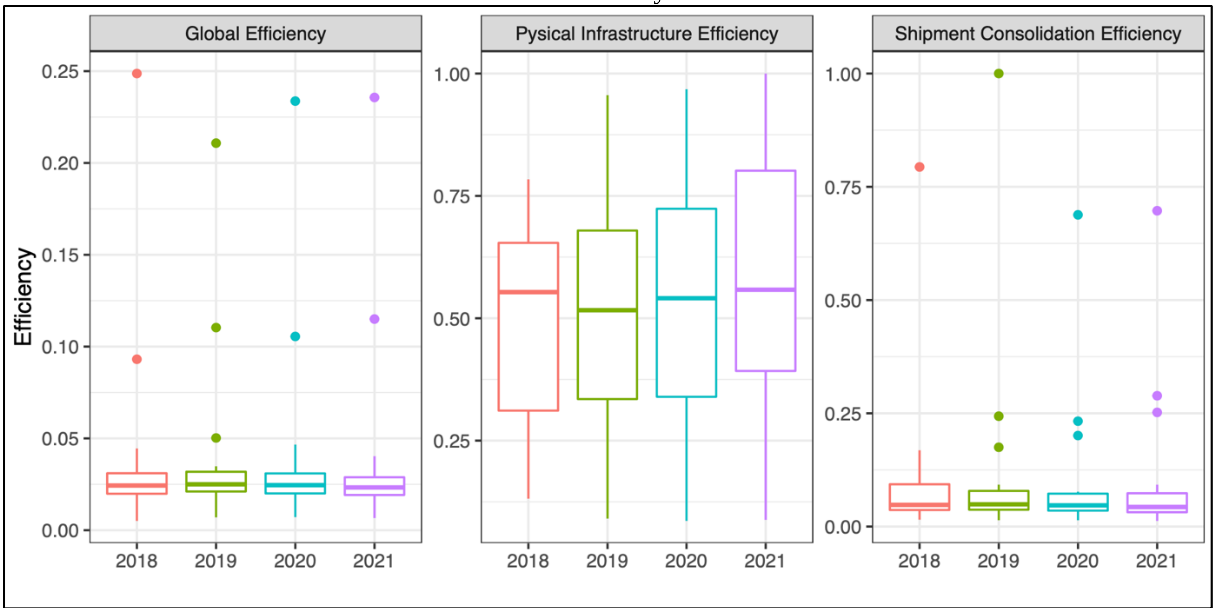

Figure 6: Consolidation of all efficiency levels

Figure 4 exhibits four different quadrants or groups (numbered clockwise starting from the upper right quadrant) delimited in four x and y graphs for each of the four periods. DMUs located in Group no. 1 exhibit both relatively high physical infrastructure and shipment consolidation efficiency levels. DMUs located in Group no. 2, on the other hand, consist of relatively low physical infrastructure and high shipment consolidation efficiency levels. Group no. 3 contains DMUs with both relatively low physical infrastructure and shipment consolidation efficiency levels. Finally, physical infrastructure efficiency levels of DMUs in Group no. 4 are relatively high in contrast to their shipment consolidation ones.

Complementarily, figure 5 presents the probabilities scores of each of the two stages' efficiency levels while figure 6 depicts the consolidation of all efficiency levels for each of the four periods. Finally, table 4 brings an efficiency summary for each terminal.

Table 4: Efficiency summary for each terminal

Terminals	Years	Global Efficiency	Physical Infrastructure Efficiency	Shipment Consolidation Efficiency
DP World Santos	2018	0,01851	0,55382	0,03342
	2019	0,02700	0,67721	0,03986
	2020	0,03008	0,77380	0,03887
	2021	0,02820	0,80112	0,03520
Imbituba	2018	0,02059	0,13147	0,15663
	2019	0,01587	0,09069	0,17499
	2020	0,01727	0,08596	0,20093
	2021	0,02222	0,08815	0,25203
Itaguai	2018	0,01446	0,29410	0,04915
	2019	0,01370	0,20191	0,06783
	2020	0,01400	0,18691	0,07490
	2021	0,01290	0,13958	0,09240
Itajai	2018	0,03471	0,77308	0,04489
	2019	0,02733	0,71835	0,03804
	2020	0,03049	0,86058	0,03543
	2021	0,02605	0,80268	0,03245
Paranagua	2018	0,02393	0,47109	0,05079
	2019	0,02572	0,53260	0,04830
	2020	0,02658	0,56743	0,04684
	2021	0,02437	0,63853	0,03817
Porto Chibatao	2018	0,00506	0,33391	0,01516
	2019	0,00699	0,50034	0,01397
	2020	0,00711	0,51437	0,01383
	2021	0,00663	0,53260	0,01245
Porto Itapoa	2018	0,02862	0,76045	0,03763
	2019	0,03106	0,89526	0,03469
	2020	0,02851	0,83308	0,03422
	2021	0,02743	0,93160	0,02944
Portonave	2018	0,01802	0,56502	0,03189
	2019	0,01845	0,55465	0,03326
	2020	0,02041	0,70697	0,02886
	2021	0,02204	0,85387	0,02582
Rio de Janeiro T1	2018	0,02377	0,25465	0,09333
	2019	0,02425	0,31339	0,07739

	2020	0,02174	0,31419	0,06919
	2021	0,01922	0,28130	0,06834
Rio de Janeiro T2	2018	0,02335	0,24974	0,09350
	2019	0,02160	0,26174	0,08251
	2020	0,01900	0,26433	0,07186
	2021	0,02202	0,52993	0,04155
Rio Grande	2018	0,02475	0,53079	0,04662
	2019	0,02315	0,48611	0,04763
	2020	0,02186	0,48296	0,04526
	2021	0,01963	0,45062	0,04356
Salvador	2018	0,04452	0,64272	0,06927
	2019	0,05024	0,66830	0,07517
	2020	0,04668	0,66488	0,07020
	2021	0,04030	0,67094	0,06007
Santos BTP	2018	0,01834	0,78382	0,02340
	2019	0,02136	0,95582	0,02234
	2020	0,02116	0,96793	0,02186
	2021	0,01909	1,00000	0,01909
Santos Santos Brasil	2018	0,02032	0,76751	0,02648
	2019	0,02032	0,89100	0,02281
	2020	0,01851	0,83528	0,02216
	2021	0,01831	1,00000	0,01831
Suape	2018	0,02697	0,58140	0,04639
	2019	0,02884	0,63354	0,04551
	2020	0,02655	0,62307	0,04261
	2021	0,02516	0,58391	0,04309
Super Terminais Manaus	2018	0,02564	0,66714	0,03843
	2019	0,02300	0,34203	0,06724
	2020	0,02260	0,33948	0,06658
	2021	0,01903	0,37428	0,05085
Terminal Portuario do Pecem	2018	0,03024	0,30508	0,09912
	2019	0,03482	0,37649	0,09249
	2020	0,03233	0,42008	0,07697
	2021	0,03881	0,43613	0,08898
Terminal Santa Clara	2018	0,24870	0,31330	0,79381
	2019	0,21080	0,21080	1,00000
	2020	0,23370	0,33964	0,68809
	2021	0,23567	0,33805	0,69717
Vila do Conde	2018	0,09311	0,55306	0,16835
	2019	0,11035	0,45301	0,24359
	2020	0,10552	0,45353	0,23267
	2021	0,11500	0,39827	0,28876
Vitoria Tvv	2018	0,03344	0,64971	0,05148
	2019	0,03414	0,68516	0,04983
	2020	0,03303	0,70482	0,04686
	2021	0,03080	0,71293	0,04320

Source: elaborated by the author

4.2 MALMQUIST INDEX

Following below are findings obtained from performing the Malmquist index analysis on all three pairs of data sets from the four twelve-month periods, mostly consisting of basic statistical sample traits of each pair (table 5 below), relevant displays of productivity changes over time and additional data.

Table 5: Malmquist index basic statistical sample traits

Pairs	Statistics	Malmquist Index (M)	Technical Change (TC)	Efficiency Change (EC)
MAR2018-FEB2019/ MAR2019-FEB2020	Mean	1,04605	0,94165	1,11583
	Standard Deviation	0,16635	0,07509	0,19534
	Coefficient of Variation	0,15903	0,07975	0,17507
MAR2019-FEB2020/ MAR2020-FEB2021	Mean	0,98827	1,02190	0,97049
	Standard Deviation	0,07455	0,06679	0,09045
	Coefficient of Variation	0,07544	0,06535	0,09321
MAR2020-FEB2021/ MAR2021-FEB2022	Mean	0,97548	1,04764	0,93191
	Standard Deviation	0,11932	0,03920	0,11606
	Coefficient of Variation	0,12232	0,03742	0,12454

Source: elaborated by the author

4.2.1 March 2018 to February 2019 - March 2019 to February 2020 (“before” the pandemic)

In general, the sample’s calculated M of 1,04 indicates the majority of DMUs are at a fairly good productivity status (over 1,00). DP World Santos, Porto Chibatão, Santos BTP, Terminal Portuario do Pecem and Salvador top the rank. On the other hand, Rio Grande, Rio de Janeiro T2, Super Terminais Manaus, Itajaí and Imbituba are at the bottom. This situation will change substantially as shown below as time progresses and the pandemic strikes. Also, Terminal Santa Clara is the only terminal with both TC and EC levels at exactly 1,00.

In addition, it is worth noticing the EC level is at its highest (1,11) at the same time the TC one (0,94) is at its lowest. Over time these levels will also modify.

4.2.2 March 2019 to February 2020 - March 2020 to February 2021 (“during” the pandemic)

With the onset of the pandemic there is a slight decrease in the overall M (0,98) indicating the majority of DMUs have not seen any changes deemed relevant in their productivity status albeit most of their indexes is now below 1,00. DP World Santos, Porto Chibatão, Salvador, Santos BTP and Terminal Portuario do Pecem experience the greatest index reductions while Itajai and Imbituba see their indexes highly improve. Terminal Santa Clara remains as the only terminal with both TC and EC levels at 1,00. Moreover, the EC level falls to about 0,97 while the TC one rises (1,02).

4.2.3 March 2020 to February 2021 - March 2021 to February 2022 (“after” the pandemic)

The transition between COVID-19 pandemic’s first year and the following twelve months bring about another mild decrease in the overall M (0,97) indicating the majority of DMUs have still not seen any significant changes in their productivity status even though almost all indexes are now below 1,00. Itajai reverses course and now joins DP World Santos, Porto Chibatão, Salvador and Santos BTP in their downtrend movement. In turn, Rio de Janeiro T2 and Terminal Portuario do Pecem now act in accordance with Imbituba’s index improvement. Terminal Santa Clara once again is the only terminal with both TC and EC levels at 1,00. Furthermore, the EC level decreases (0,93) at the same time the TC one increases (1,04).

4.2.4 Malmquist Index Special Cases

In essence, nearly all sample DMUs experienced minor M variances in each one of the three pairs and none of them consolidated a relatively high/low ranking position. Significant upwards (Imbituba and Rio de Janeiro T2) and downwards (DP World Santos, Porto Chibatão, Santos BTP and Salvador) changes were noticed; relevant high-and-low (Itajaí) and low-and-high (Terminal Portuario do Pecem) movements were observed and, once more, Terminal Santa Clara preserved its indexes while maintaining an upper trend.

4.2.5 Malmquist Index Representation

The M, TC and EC levels calculated for each of the 20 DMUs in all three pairs of data sets from the four twelve-month periods are given in the figure and table below.

As shown in figure 7 the DMUs sample selected for this study exhibited a decline in their EC levels despite the TC levels improvement, resulting in an overall downtrend of M. In turn, table 6 reveals only 5 out of the 20 terminals evaluated in this study indicated an end-to-end efficiency improvement (Imbituba, Itajaí, Portonave, Rio de Janeiro T2 and Terminal Portuario do Pecem), one (Terminal Santa Clara) preserved its EC and TC indices and another four displayed considerable decreases (DP World Santos, Porto Chibatão, Santos BTP and Salvador) as previously mentioned.

Source: elaborated by the author

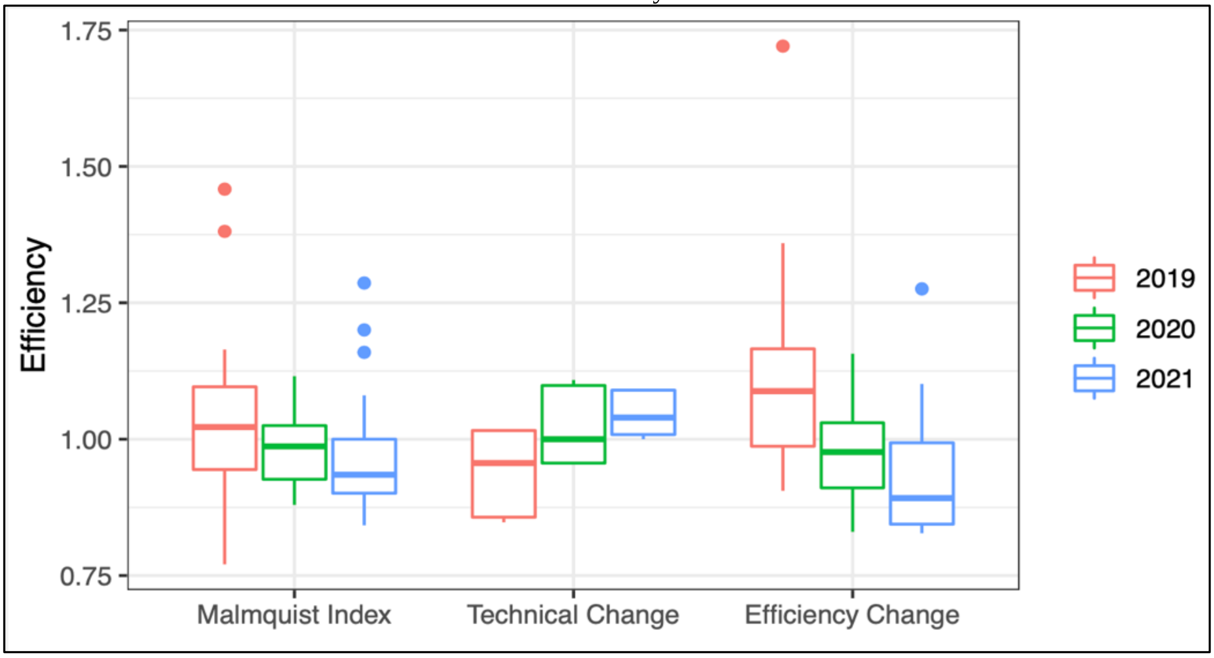

Figure 7: Malmquist index, technical change and efficiency change

Table 6: Malmquist index, technical change and efficiency change summary for each terminal

Terminals	Years	Malmquist Index	Technical Change	Efficiency Change
DP World Santos	2019	1,45833	0,84762	1,72051
	2020	1,11429	1,10861	1,00512
	2021	0,93732	1,00845	0,92947
Imbituba	2019	0,77061	0,84762	0,90915
	2020	1,08837	1,10861	0,98174
	2021	1,28632	1,00845	1,27555
Itaguai	2019	0,94737	1,01587	0,93257
	2020	1,02222	0,95625	1,06899
	2021	0,92120	1,08987	0,84523
Itajai	2019	0,78742	0,86966	0,90544
	2020	1,11570	1,08530	1,02801
	2021	0,85432	1,01942	0,83804
Paranagua	2019	1,07506	1,01587	1,05826
	2020	1,03330	0,95625	1,08057
	2021	0,91684	1,08987	0,84124
Porto Chibatao	2019	1,38095	1,01587	1,35938
	2020	1,01724	0,95625	1,06378
	2021	0,93220	1,08987	0,85534
Porto Itapoa	2019	1,08523	1,01587	1,06827
	2020	0,91798	0,95625	0,95997
	2021	0,96198	1,08987	0,88265
Portonave	2019	1,02372	1,01587	1,00772
	2020	1,10618	0,95625	1,15679
	2021	1,08028	1,08987	0,99120
Rio de Janeiro T1	2019	1,02048	0,92123	1,10773
	2020	0,89632	1,03511	0,86592
	2021	0,88433	1,04474	0,84646
Rio de Janeiro T2	2019	0,92487	1,01587	0,91042
	2020	0,87955	0,95625	0,91979
	2021	1,15924	1,08987	1,06365

Rio Grande	2019	0,93557	0,98666	0,94822
	2020	0,94405	0,97897	0,96432
	2021	0,89818	1,07612	0,83465
Salvador	2019	1,12842	0,84762	1,33128
	2020	0,92910	1,10861	0,83808
	2021	0,86345	1,00845	0,85622
Santos BTP	2019	1,16440	1,01587	1,14621
	2020	0,99093	0,95625	1,03627
	2021	0,90196	1,08987	0,82759
Santos Santos Brasil	2019	1,00000	0,85813	1,16532
	2020	0,91100	1,09734	0,83019
	2021	0,98915	1,01370	0,97578
Suape	2019	1,06920	0,84762	1,26141
	2020	0,92067	1,10861	0,83047
	2021	0,94785	1,00845	0,93991
Super Terminais Manaus	2019	0,89691	0,85374	1,05057
	2020	0,98276	1,10202	0,89178
	2021	0,84211	1,01150	0,83253
Terminal Portuario do Pecem	2019	1,15157	1,01587	1,13357
	2020	0,92847	0,95625	0,97095
	2021	1,20031	1,08987	1,10133
Terminal Santa Clara	2019	1,00000	1,00000	1,00000
	2020	1,00000	1,00000	1,00000
	2021	1,00000	1,00000	1,00000
Vila do Conde	2019	1,08012	0,92582	1,16667
	2020	1,00000	1,00000	1,00000
	2021	1,00000	1,00000	1,00000
Vitoria Tvv	2019	1,02083	0,90027	1,13392
	2020	0,96735	1,05482	0,91708
	2021	0,93249	1,03451	0,90138

Source: elaborated by the author

4.3 UNPAIRED TWO-SAMPLES WILCOXON TEST

In order to determine whether or not the global M decrease is statistically significant an unpaired two-samples Wilcoxon test was conducted; table 7 outlines its results. From a broader perspective these numbers clarify what figure 7 had already visually demonstrated. Significant EC to lower standards are noticed when comparing the moments before the pandemic and during the pandemic, and also before and after it; however, significant TC to higher levels are simultaneously observed in the very same two pairs of data sets. Since the decreasing change of the former outperforms the increasing one of the latter the overall M results also indicate an ultimate downtrend but in a smoother fashion than EC, one that – and here is the core finding – is only considered statistically significant when the furthest apart moments are compared (before and after the pandemic hit).

Therefore, under this study's premises there was no indication of a relevant impact on the efficiency of Brazil's major container terminals derived from the COVID-19 pandemic outbreak. To put it in another way, it seems that this SC disruption did not have a significant role in the general efficiency decrease of herein addressed container terminals.

Table 7: Unpaired two-samples Wilcoxon test results

Malmquist Index			
Pair 1	Pair 2	P-Value (greater)	Result
MAR2018-FEB2019/ MAR2019-FEB2020	MAR2019-FEB2020/ MAR2020-FEB2021	0,07389	No significant difference
MAR2018-FEB2019/ MAR2019-FEB2020	MAR2020-FEB2021/ MAR2021-FEB2022	0,03192	There is a significant difference
MAR2019-FEB2020/ MAR2020-FEB2021	MAR2020-FEB2021/ MAR2021-FEB2022	0,14571	No significant difference
Technical Change			
Pair 1	Pair 2	P-Value (lower)	Result
MAR2018-FEB2019/ MAR2019-FEB2020	MAR2019-FEB2020/ MAR2020-FEB2021	0,00568	There is a significant difference
MAR2018-FEB2019/ MAR2019-FEB2020	MAR2020-FEB2021/ MAR2021-FEB2022	0,00014	There is a significant difference
MAR2019-FEB2020/ MAR2020-FEB2021	MAR2020-FEB2021/ MAR2021-FEB2022	0,12499	No significant difference
Efficiency Change			
Pair 1	Pair 2	P-Value (greater)	Result
MAR2018-FEB2019/ MAR2019-FEB2020	MAR2019-FEB2020/ MAR2020-FEB2021	0,00281	There is a significant difference
MAR2018-FEB2019/ MAR2019-FEB2020	MAR2020-FEB2021/ MAR2021-FEB2022	0,00012	There is a significant difference
MAR2019-FEB2020/ MAR2020-FEB2021	MAR2020-FEB2021/ MAR2021-FEB2022	0,07391	No significant difference

Source: elaborated by the author

4.4 DISCUSSION

The absence of statistical significance in the period changes between the moments during and after the pandemic onset in all three factors’ discoveries should be highlighted. When comparing it with the statistical significance of the period change between the moments before and during the pandemic outbreak, the insignificant decrease of M was the product of a relatively modest increment in TC and a corresponding small reduction in EC. This suggests there could have been an overall tendency at the time among top management of hereby studied terminals to partially shift efforts from technological/procedural improvements to the preservation of ongoing operations. Such understanding is confirmed by the interviewed officials’ opinions on the matter indicating a general effort led by Brazilian federal government authorities to assure port operations would not be considerably affected by the pandemic outbreak.

Truly, according to the container sector's interviewed officials, the general efficiency reduction ultimately revealed seems to derive from reasons other than the pandemic's outbreak. Some of them are container terminal's operational adjustments required by ship size increases over the years and a previous well-known predisposition of main shipowners to shift vessel calls to their own terminals or ones deemed more efficient, evidencing their bargaining power in the maritime market. In the same line of thought, a recent in-depth study conducted by ANTAQ unveiled shipment frequency numbers from Brazilian container terminals remained quite stable; in practice, some of the main concerns among port authorities were related to rising freight rates, ship scale omissions and other general logistical arrangements made to mitigate the effects of the container crisis and preserve operations (Brasil, 2022b).

On a broader context, there is a growing need for transparency and visibility in vessel dynamics across maritime trade networks to better deal with SC disruptions. In these circumstances increasing freight rates are one of the expected outcomes, as it occurred during COVID-19; correspondingly, data sharing and time slots can empower port authorities through more informed decisions, flexible practices and plans. Under the "slot management" concept, it directly promotes a just-in-time vessel arrival approach while simultaneously enables a synchronized movement across the global intermodal SC consisting of a stakeholder network of manufacturers, logistics providers, retailers, consumers, as well as infrastructure, resources, and processes (Lind, Lehmacher, Hoffmann, Jensen, Notteboom, Rydbergh, Sand, Haraldson, White, Becha & Berlund, 2022).

UNCTAD's Liner Shipping Connectivity Index (LSCI) captures how connected countries are to global shipping networks and is based on five components of the maritime transport sector: number of shipping lines servicing a country, size of the largest vessel used on these services, number of services connecting a country to the other countries, total number of vessels deployed in a country and total capacity of those vessels. Ultimately, the LSCI can be considered both a measure of connectivity to maritime shipping and one of trade facilitation, evidencing container shipping lines' strategies of maximizing profits through market coverage (Niérat & Guerrero, 2019; Notteboom, Pallis, & Rodrigue, 2022b).

In line with these trends, Brazilian Ministry of Infrastructure's "Porto Sem Papel" facilitates routine port operations across the country by concentrating information about vessels in a single online database, making it a reliable platform for general port operations' logs (i.e., berthing and unberthing stages of vessels), processing of bureaucratic documents by maritime agents and so on (Brasil, 2022e).

5 CONCLUSION

Over the years not only standard businesses but also the maritime industry has experimented continued economic cycles, many of these occasionally affected by unexpected disturbing events that negatively impacted trade practices. Be that as it may, maritime SC disruptions simultaneously represent a challenge and an ideal event for global port and shipping industries to identify weaknesses, make adjustments and adapt to shifting circumstances in pursuance of building disruption resilience. The COVID-19 pandemic is no different. Lockdowns, demand surge, rising container freight rates, container imbalances worldwide provoked port call shifts, substantial capacity management and the necessary adoption of personnel safety measures without harming operational capabilities - all signs of system adaptability and the ability to overcome obstacles.

Given these circumstances it is advisable to not only monitor port performance but dive into the topic of port efficiency for the sake of determining a port's capability to withstand SC disruptions' consequences. Following the theoretical lenses of two-stage network DEA combined with Malmquist index, this study analyzed the major Brazilian container ports/terminals in order to determine the impact of COVID-19 pandemic on their efficiency. Based on secondary data for a set of 20 Brazilian container ports/terminals gathered from port authorities' websites and federal government documents, reports and databases, the findings indicate that the majority of terminals exhibit slight decreasing efficiency, suggesting the COVID-19 pandemic did not have a significant impact on the efficiency of the country's major container terminals. This is corroborated by Guidorizzi, Mendes, Carvalho and Arévalo (2022) which disclosed that, of all main Brazilian transport modes, sea freight was the one where the crisis effects were least substantial.

This research adds to the vast body of literature on port efficiency and enhances the understanding of SC disruption impact on maritime SC. Nevertheless, it is not exempted from limitations. Although the quantitative method provides embracing numerical analysis that contribute to data-driven decision-making, the qualitative one has a greater potential to investigate a particular object of study in a more in-depth fashion. In addition, DEA is merely one of the techniques at hand to quantitatively discover the efficiency of a set of DMUs, as shown in previous pages.

The impact of COVID-19 pandemic on Brazil's major container terminals could have very well been determined differently had some of the studies elements been distinct: the timeframe analyzed, the input/output variables utilized, the use of Malmquist index due to the longitudinal analysis, the set of DMUs chosen (and/or their limited number), etc. Regarding the latter, mention should be made to the fact that the period change between the moments before and during the pandemic actually did exhibit a statistically significant result in both TC and EC levels even though M itself did not follow suit. One could argue this container terminal's market concentration hinders not only competitiveness but also ideal research conditions in the sense that, despite representing something in the region of 95 per cent of Brazil's total container throughput, a sample consisting of merely 20 DMUs might not be an ideal statistical representation. This topic sparks an important debate and should be further developed.

Also, in future research the two-stage network DEA based Malmquist approach can be applied and/or adapted to other terminals/ports or scenarios to test its feasibility in various contexts, mainly the cabotage trade which provides the feeder services delivering containers concentrated in hub ports to smaller terminals along the coast. In consonance with Brasil (2022f), feeder services represent approximately 40 per cent of the nation's cabotage navigation, with the Santos port considered the only effective Brazilian hub port, responsible for two thirds of all its transported cargo. Due to the relevance of this matter, Roberto, Matos, Gavião and Kostin (2020) confirms Brazil's commercial shipping inefficiency and indicate The Netherlands and Turkey as suitable role models in the country's attempt to develop its cabotage services.

Moreover, the adoption of quantitative variables such as static capacity and maximum draught together with contextual ones such as riverine/railroad access, public/private ownership and publicly listed business could fine-tune data analysis, provide richer information and, thus, contribute to better understanding of disruptive effects on a given set of maritime ports' DMUs. Finally, examples of worldwide SC disruptions that provide useful context for further researches abound. The Evergreen vessel's recent Suez Canal incident, the war in Ukraine, geopolitical tensions between the US and China, along with the advent of Environmental, Social and Governance (ESG) requirements under the United Nation's Agenda 2030 and even a potential onset of another pandemic are some trending topics that have also raised public awareness of how the global maritime SC is prepared for coming challenges.

REFERENCES

ABC7 Los Angeles. (2021). Record number of container ships waiting to enter ports of Los Angeles, Long Beach. Available at: https://abc7.com/port-backlog-of-los-angeles-long-beach-container-ships/11142891/ [Accessed in 12 April 2022]

Abreu, G. de S. (2018). *Amazônia, o enigma da segurança (1ª ed.)*. Editora Prismas, Curitiba.

Aigner, D., Lovell, C.A.K. & Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6(1), 21–37. doi: 10.1016/0304-4076(77)90052-5

Al-Mansour, J. & Al-Ajmi, S. (2020). Coronavirus 'COVID-19' – Supply Chain Disruption and Implications for Strategy, Economy, and Management. *Journal of Asian Finance, Economics and Business*, 7(9), 659–672. doi: 10.13106/jafeb.2020.vol7.no9.659

Al-Rodhan, N. & Stoudmann, G. (2006, June 19). Definitions of Globalization: A Comprehensive Overview and a Proposed Definition. Program on the Geopolitical Implications of Globalization and Transnational Security. Geneva Centre for Security Policy. Available at https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.472.4772&rep=rep1&type=pdf#:~:text= [Accessed 11 April 2019].

Alderton, P. (2008). *Port Management and Operations* (3rd ed.). Informa Law. London.

Andrade, R. M., Lee, S., Lee, P. T-W., Kwon, O. K. & Chung, H. M. (2019). Port Efficiency Incorporating Service Measurement Variables by the BiO-MCDEA: Brazilian Case. *Sustainability*, 11(16), 4340. doi: 10.3390/su11164340

Banker, R.D., Charnes, A. & Cooper, W.W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 30(9), 1078-1092. doi: 10.1287/MNSC.30.9.1078

Banker, R.D., Charnes, A., Cooper, W.W., Swarts, W. & Thomas, D. (1989). An introduction to data envelopment analysis with some of its models and their uses. *Research in governmental and nonprofit accounting*, 5(1), 125-163. Retrieved from: http://iiif.library.cmu.edu/file/Cooper_box0010c_fld00033_bdl0001_doc0001/Cooper_box0010c_fld00033_bdl0001_doc0001.pdf [Accessed in 26 June 2022]

Barros, C.P. & Athanassiou, M. (2004). Efficiency in European seaports with DEA: evidence from Greece and Portugal. *Maritime Economics & Logistics*, 6 (2), 122–140. doi:10.1057/palgrave.mel.9100099

Barros, C.P. & Managi, S. (2008). Productivity drivers in Japanese seaports. *Technical University of Lisbon*. Working Paper 15/2008/DE/UECE.

Barros, C.P., Felício, J.A. & Fernandes, R.L. (2012). Productivity analysis of Brazilian seaports. *Maritime Policy & Management*, 39(5), 1-21. doi:10.1080/03088839.2012.705033

Bhatnagar, R. & Teo, C. (2009). Role of Logistics in Enhancing Competitive Advantage: a Value Chain Framework for Global Supply Chains. *International Journal of Physical Distribution and Logistics Management*, 39(3), 202–226. doi: 10.1108/09600030910951700

Bhutta, K.S. & Huq, F. (1999). Benchmarking – best practices: an integrated approach. *Benchmarking: An International Journal*, 6(3), 254-68. Available at: https://www.academia.edu/19328997/Benchmarking_best_practices_an_integrated_approach

Bichou, K. (2009). A benchmarking study of the impacts of security regulations on container port efficiency (Doctoral dissertation). Imperial College London, London, England.

Bichou, K. (2011). A two-stage supply chain DEA model for measuring container-terminal efficiency. *International Journal of Shipping and Transport Logistics*, 3 (1), 6–29. doi: 10.1504/IJSTL.2011.037817

Birkie, S., Trucco, P. & Campos, P. (2017). Effectiveness of resilience capabilities in mitigating disruptions: leveraging on supply chain structural complexity. *Supply Chain Management*, 22(6), 506-521. doi: 10.1108/SCM-01-2017-0009

Blackhurst, J., Dunn, K. & Craighead, C. (2011). An empirically derived framework of globally supply chain resilience. *Journal of Business Logistics Systems and Management*, 32(4), 374-391. doi: 10.1111/j.0000-0000.2011.01032.x

Blanchard, D. (2007). Five Strategies to Avoid Port Congestion. Industry Week. Available at: https://www.industryweek.com/the-economy/article/21938004/five-strategies-to-avoid-port-congestion [Accessed in 18 May 2022]

Block, P., Hoffman, M., Raabe, I., Dowd, J., Rahal, C., Kashyap, R., & Mills, M. (2020). Social Network-Based Distancing Strategies to Flatten the COVID-19 Curve in a Post-Lockdown World. *Nature Human Behaviour*, 4, 588–596.

Bloomberg. (2022). Shipping Congestion Is Growing at World’s Biggest Port. Available at: https://www.bloomberg.com/news/articles/2022-01-13/chinese-port-congestion-grows-as-ships-try-to-avoid-virus-curbs [Accessed in 12 April 2022]

Bode, C. & Wagner, S. (2015). Structural drivers of supply chain complexity and the frequency of supply chain disruptions. *Journal of Operations Management*, 36, 215-228.

Bode, C., Wagner, S., Petersen, K. & Ellram, L. (2011). Understanding responses to supply chain disruptions: insights from information processing and resource dependence perspectives. *Academy of Management Journal*, 54(4), 833-856.

Bogetoft, P. & Otto, L. (2011). Additional Topics in DEA. In: Bogetoft, P. & Otto, L. (Eds.). (2011). *Benchmarking with DEA, SFA, and R*. International Series in Operations Research & Management Science (ISOR) 157, 115–153.

Brasil. (2022). Pelo terceiro ano seguido, Governo Federal premia destaques no setor portuário. *Ministério da Infraestrutura*. Available at: https://www.gov.br/infraestrutura/pt-br/assuntos/noticias/2022/06/pelo-terceiro-ano-seguido-governo-federal-premia-destaques-no-setor-portuario [Accessed 06 November 2022]

Brasil. (2022a). e-Navigation traz mais segurança e aprimora a navegação. *Marinha do Brasil – Agência Marinha de Notícias*. Available at: https://www.marinha.mil.br/agenciadenoticias/e-navigation-traz-mais-seguranca-e-aprimora-navegacao [Accessed 09 November 2022]

Brasil. (2022b). Grupo de Trabalho de monitoramento dos impactos da pandemia da Covid-19 no Transporte Marítimo e no Setor Portuário. *Agência Nacional de Transportes Aquiaviários (ANTAQ)*. Available at: https://www.gov.br/antaq/pt-br/noticias/2022/relatorio-detalha-impactos-da-pandemia-da-covid-19-no-transporte-maritimo/relatorio-final-gt-transporte-maritimo-v1.pdf [Accessed 22 November 2022]

Brasil. (2022c). Comissão Nacional de Segurança Pública nos Portos, Terminais e Vias Navegáveis - Conportos. *Ministério da Justiça e Segurança Pública*. Available at: https://www.gov.br/pf/pt-br/assuntos/seguranca-portuaria/conportos [Accessed 03 December 2022]

Brasil. (2022d). Amazônia Azul. *Marinha do Brasil*. Available at: https://www.mar.mil.br/hotsites/amazonia_azul/ [Accessed 27 December 2022]

Brasil. (2022e). Atualização do Porto Sem Papel reduz tempo de operações e aumenta eficiência da plataforma. *Ministério de Infraestrutura*. Available at: https://www.gov.br/infraestrutura/pt-br/assuntos/noticias/2022/05/atualizacao-do-porto-sem-papel-reduz-tempo-de-operacoes-e-aumenta-eficiencia-da-plataforma [Accessed 29 December 2022]

Brasil. (2022f). Quantificação do mercado feeder na cabotagem brasileira. *Agência Nacional de Transportes Aquaviários (ANTAQ)*. Available at: https://www.gov.br/antaq/pt-br/central-de-conteudos/estudos-e-pesquisas-da-antaq-1/Quantificacao_do_feeder.pdf [Accessed 30 December 2022]

Brouer, B., Dirksen, J., Pisinger, D., Plum, C. & Vaaben, B. (2013). The vessel schedule recovery problem (VSRP) – A MIP model for handling disruptions in liner shipping. *European Journal of Operational Research*, 224(2), 362 – 374. doi: 10.1016/j.ejor.2012.08.016

Bugert, N. & Lasch, R. (2018). Supply Chain Disruption Models: A Critical Review. *Logistics Research*, 11(5), 1-35. doi: 10.23773/2018_5

Burns, M.G. (2015). *Port Management and Operations*. doi: 10.4324/9781315275215

Carter, C.A., Steinbach, S. & Zhuang, X. (2021). 'Containergeddon' and California agriculture. *ARE Update*, 25(2), 1–4.

Carvalho, V., Nirei, M., Saito, Y. & Tahbaz-Salehi, A. (2021). Supply Chain Disruptions: Evidence from the Great East Japan Earthquake. *The Quarterly Journal of Economics*, 136(2), 1255–1321. doi: 10.1093/qje/qjaa044

Castellano, R., Fiore, U., Musella, G., Francesca, P., Punzo, G., Risitano, M., Sorrentino, A. & Zanetti, P. (2019). Do Digital and Communication Technologies Improve Smart Ports? A Fuzzy DEA Approach. *IEEE Transactions on Industrial Informatics*, 15(10), 5674-568. doi: 10.1109/TII.2019.2927749.

Chang, V. & Tovar, B. (2014). Drivers explaining the inefficiency of Peruvian and Chilean ports terminals. *Transportation Research Part E: Logistics and Transportation Review*, 67, 190-203. doi: 10.1016/j.tre.2014.04.011

Charles, D. (2020). Food shortages? Nope, too much food in the wrong places. The Salt, on National Public Radio. Available at: https://www.npr.org/sections/thesalt/2020/04/03/ 826006362/food-shortages-nope-too-much-food-in-the-wrongplaces?utm_campaign5 storyshar%E2%80%A6 [Accessed in 29 April 2022]

Charnes, A., Cooper, W.W. & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2(6), 429–444. doi: 10.1016/0377-2217(78)90138-8G

Charnes, A., Cooper, W., Lewin, A. & Seifort, L. (1994). Data Envelopment Analysis. Kluwer, Boston

Chelin, R. & Reva, D. (2020). Security vs efficiency: smart ports in a post-COVID-19 era. *Institute for Security Services*. Available at: https://issafrica.org/iss-today/security-vs-efficiency-smart-ports-in-a-post-covid-19-era [Accessed 29 November 2022]

Childerhouse, P. & Towill, D. (2003). Simplified Material Flow Holds the Key to Supply Chain Integration. *Omega*, 31(1), 17–27. doi:10.1016/S0305-0483(02)00062-2

Chopra, S. & Meindl, P. (2013). *Supply chain management: Strategy, planning & operation. Global Edition (5th ed.)*. Pearson Education. Harlow.

Chopra, S. & Sodhi, M. (2004). Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review*, 46(1), 52-61.

Chopra, S. & Sodhi, M. (2014). Reducing the risks of supply chain disruptions. *MIT Sloan Management Review*, 55(3), 73-80.

Christopher, M. & Peck, H. (2004). Building the resilient supply chain. *The International Journal of Logistics Management*, 15(2), 1-13.

Christopher, M. & Peck, H., (2003). Building the resilient supply chain. *International Journal of Logistics Management*, 15, 1–14.

Christopher, M., Peck, H. & Towill, D. (2006). A taxonomy for selecting global supply chain strategies. *International Journal of Logistics Management,* 2(2) , 277–287.

Chryssolouris, G., Makris, S., Xanthakis, V. & Mourtzis, D. (2004). Towards the internet-based supply chain management for the ship repair industry. *International Journal of Computer Integrated Manufacturing*, 17(1), 45–57. doi: 10.1080/0951192031000080885

Clausen, J., Larsen, A., Larsen, J. & Rezanova, N. (2010). Disruption management in the airline industry-concepts, models and methods. *Computers & Operations Research*, 37(5), 809 – 821. doi: 10.1016/j.cor.2009.03.027

CNN Business. (2022). Port delays are getting worse in Shanghai. That's very bad news for global supply chains. Available at: https://edition.cnn.com/2022/04/01/business/shanghai-covid-port-delays-global-impact-intl-hnk/index.html [Accessed in 12 April 2022]

Colicchia, C. (2019). Information sharing in supply chains: A review of risks and opportunities using the systematic literature network analysis (slna). *Supply Chain Management: An International Journal*, 24(1), 5-21.

Collinson, S. & Jay, M. (2012). *From Complexity to Simplicity: Unleash Your Organization's Potential.* Palgrave McMillan, London.

Cooper, W., Seiford, L. & Zhu, J. (2011). Data Envelopment Analysis: History, Models, and Interpretations. In Cooper, W., Seiford, L. & Zhu, J. (2011). *Handbook on Data Envelopment Analysis*. International Series in Operations Research & Management Science (ISOR) 164, 1-39.

Cooper, W.W., Seiford, L.M. & Tone, K. (2007). *Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software (2nd ed.)*. Springer, New York. Retrieved from: https://link.springer.com/book/10.1007/978-0-387-45283-8

Craighead, C., Blackhurst, J., Rungtusanatham, M. & Handfield, R. (2007). The severity of supply chain disruptions: design characteristics and mitigation capabilities. *Decision Sciences*, 38(1), 131-156.

Creazza, A., Dallari, F. & Melacini, M. (2010). Evaluating logistics network configurations for a global supply chain. *Supply Chain Management An International Journal*, 15(2), 54–164.

Creswell, J. W. (2018). Research Design: Qualitative, Quantitative and Mixed Methods Approaches. Retrieved from https://fe.unj.ac.id/wp-content/uploads/2019/08/Research-Design_Qualitative-Quantitative-and-Mixed-Methods-Approaches.pdf

Cruz, C. & Marques, R. (2012). Risk-Sharing in Seaport Terminal Concessions. *Transport Reviews*, 32(4), 455-471. doi: 10.1080/01441647.2012.664576

Cullinane K. P. B., Song D.-W. & Wang T.F. (2005) The application of mathematical programming approaches to estimating container port production efficiency. *Journal of Productivity Analysis*, 24(1), 73–92. doi: 10.1007/s11123-005-3041-9

Cullinane, K. & Song, D. (2003). A stochastic frontier model of the productive efficiency of Korean terminals. *Applied Economics*, 35(3), 251–267. doi: 10.1080/00036840210139355

Cullinane, K. & Song, D. (2003). A stochastic frontier model of the productive efficiency of Korean terminals. *Applied Economics*, 35(3), 251–267. doi: 10.1080/00036840210139355

Cullinane, K., Wang, T.-F., Song, D.-W. & Ji, P. (2006). The technical efficiency of container ports: Comparing data envelopment analysis and stochastic frontier analysis. *Transportation Research Part A: Policy and Practice*, 40, 354–374. doi: 10.1016/j.tra.2005.07.003

Cullinane, K.P.B., Song, D.-W., Ji, P. & Wang, T.-F. (2004). An application of DEA windows analysis to container port production efficiency. *Review of Network Economics*, 3(2), 186–208. doi: 10.2202/1446-9022.1050

da Silva, E., Ramos, M., Alexander, A. & Jabbour, C. (2020). A systematic review of empirical and normative decision analysis of sustainability-related supplier risk management. *Journal of Cleaner Production*, 244, 118808.

Dang., S. & Chu, L. (2016). Evaluation framework and verification for sustainable container management as reusable packaging. *Journal of Business Research*, 69(5), 1949-1955. doi: 10.1016/j.jbusres.2015.10.086

De Langen, P. (2004). Governance in Seaport Clusters. *Maritime Economics & Logistics*, 6(2), 141-156. doi:10.1057/palgrave.mel.9100100

De Langen, P. & Van der Lugt, L. (2017). Institutional reforms of authorities in the Netherlands: The establishment of port development companies. *Research in Transportation & Business Management*, 22, 108–113.

De Langen, P., Nijdam, M. & Horst, M. (2007). New Indicators to Measure Port Performance. *Journal of Maritime Research*, 4(1), 23-36

Discover Containers. (2021). Shipping Container History: Boxes to Buildings. Available at: https://www.discovercontainers.com/a-complete-history-of-the-shipping-container/ [Accessed in 10 May 2022]

Disney, S. & Towill, D. (2003). The Effect of Vendor Managed Inventory Dynamics on the Bullwhip Effect in Supply Chains. *International Journal of Production Economics*, 85(2), 199-215. doi:10.1016/S0925-5273(03)00110-5

Dolgui, A., Dmitry I. & Boris S. (2020). Reconfigurable Supply Chain: The X-Network. *International Journal of Production Research*, 58(13), 4138–4163.

Dunkley, D. (2020). Cashierless stores and online deliveries are the future of supermarket shopping. Stuff.co.nz. Available at: https://www.stuff.co.nz/business/better-business/120587848/cashierless-stores-and-online-deliveries-are-the-future-of-supermarket-shopping?r%E2%80%A6 [Accessed in 28 April 2022]

Eastwood, B. (2022). Supply chain resilience in a state of steady disruption. *MIT Sloan School of Management*. Available at: https://mitsloan.mit.edu/ideas-made-to-matter/supply-chain-resilience-a-state-steady-disruption [Accessed 09 December 2022]

Economic Commission for Latin America and the Caribbean (ECLAC). (2020). The effects of the coronavirus disease (COVID-19) pandemic on international trade and logistics. Special Report COVID-19, No. 6. Available at: https://www.cepal.org/en/publications/45878-effects-coronavirus-disease-covid-19-pandemic-international-trade-and-logistics [Accessed in 19 April 2022]

Economic Commission for Latin America and the Caribbean (ECLAC). (2021). 2020 Port Report: the impact of the coronavirus disease (COVID-19) pandemic on the shipping trade, transshipment and throughput of container ports in Latin America and the Caribbean. Available at: https://www.cepal.org/en/publications/47017-2020-port-report-impact-coronavirus-disease-covid-19-pandemic-shipping-trade [Accessed in 19 April 2022]

El Baz, J. & Ruel, S. (2021). Can supply chain risk management practices mitigate the disruption impacts on supply chains’ resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era. *International Journal of Production Economics*, 233, 1-12.

European Commission. (2013). Communication from the Commission to the European Parliament, The Council and the European Economic and Social Committee on Customs Risk Management and Security of the Supply Chain. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52012DC0793 [Accessed in 30 April 2022]

Fahimnia, B., Tang, C., Davarzani, H. & Sarkis, J. (2015). Quantitative models for managing supply chain risks: A review. *European Journal of Operational Research*, 247(1), 1-15.

Farranha, A. C., Frezza, C. da S. & Barbosa, F. de O. (2015). Nova lei dos portos: desafios jurídicos e perspectivas de investimentos. *Revista Direito GV*, 11(1), 89-116. doi: 10.1590/1808-2432201505

Farrell, M. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society: Series A*, 120(3), 253-290. doi: 10.2307/2343100

Federal Emergency Management Agency (FEMA). (2020). FEMA COVID-19 Supply Chain Task Force: Supply Chain Stabilization. Available at: https://www.fema.gov/news-release/20200725/nhom-cong-tac-chuoi-cung-ung-trong-dai-dich-covid-19-cua-fema-dinh-chuoi-cung [Accessed in 27 April 2022]

Ferrari, C., Parola, F. & Tei, A. (2015). Governance models and port concessions in Europe: Commonalities, critical issues and policy perspectives. *Transport Policy*, 41, 60–67. doi: 10.1016/j.tranpol.2015.03.012

Flexport. (2022). TEU (Twenty-foot Equivalent Unit). Available at: https://www.flexport.com/glossary/twenty-foot-equivalent-unit/ [Accessed in 11 May 2022]

Francesco, M., Lai, M. & Zuddas, P. (2013). Maritime repositioning of empty containers under uncertain port disruptions. *Computers & Industrial Engineering*, 64(3), 827-837. doi: 10.1016/j.cie.2012.12.014

Frankel, E. (1999). The economics of total trans-ocean supply chain management. *International Journal of Maritime Economics*, 1(1), 61–69. doi: 10.1057/ijme.1999.5

Fransoo, J. & Lee, C. (2013). The Critical Role of Ocean Container Transport in Global Supply Chain Performance. *Production and Operations Management*, 22(2), 253–268. doi: 10.1111/j.1937-5956.2011.01310.x

Freightos. (2022). Freightos Baltic Index (FBX): Global Container Freight Index. Available at: https://fbx.freightos.com/ [Accessed in 11 April 2022]

Frémont, A. (2009). Shipping lines and logistics. *Transport Reviews*, 29(4), 537-554. doi:10.1080/01441640802677607

Fried, H.O., Lovell, C.A.K., Schmidt, S.S. & Yaisawarng, S. (2002). Accounting for environmental effects and statistical noise in Data Envelopment Analysis. *Journal of Productivity Analysis*, 17 (1–2), 157–174. doi: 10.1023/A:1013548723393

Garcia, B. T. de G., da Silva, M. A. V., & de Freitas, M. A. V. (2017). Analysis of efficiency in the generation of waste in general cargo port terminals using DEA. *Revista Produção E Desenvolvimento*, 3(1), 60-79. doi: 10.32358/rpd.2017.v3.203

Garvey, M., Carnovale, S. & Yeniyurt, S. (2015). An analytical framework for supply network risk propagation: A Bayesian network approach. *European Journal of Operational Research*, 243, 618-627.

Ghadge, A., Wurtmann, H., & Seuring, S. (2020). Managing climate change risks in global supply chains: A review and research agenda. *International Journal of Production Research*, 58(1), 44-64.

Ghasemi, M.R., Ignatius, J. & Emrouznejad, A. (2014). A bi-objective weighted model for improving the discrimination power in MCDEA. *European Journal of Operational Research*, 233(3), 640–650. doi: 10.1016/j.ejor.2013.08.041

Golan, M., Laura H. & Igor L. (2020). Trends And Applications Of Resilience Analytics In Supply Chain Modeling: Systematic Literature Review In The Context Of The COVID-19 Pandemic. *Environment Systems and Decisions*, 40, 222–243.

Golany, B.A. & Roll, Y. (1989). An application procedure for data envelopment analysis. *Omega*, 17(3), 237-250. doi: 10.1016/0305-0483(89)90029-7

González, M. M. & Trujillo, L. (2009). Efficiency Measurement in the Port Industry: A Survey of the Empirical Evidence. *Journal of Transport Economics and Policy*, 43(2), 157–192.

Gui, D., Wang, H. & Yu, M. (2022). Risk Assessment of Port Congestion Risk during the COVID-19 Pandemic. *Journal of Marine Science and Engineering*, 10(2), 150. doi: 10.3390/jmse10020150

Guidorizzi, F. A., Mendes, G. R., Carvalho, J. P. de & Arévalo, J. L. S. (2022). Effect of the pandemic caused by covid-19 on the Brazilian market share: an approach according to the types of transport mode. *Research, Society and Development*, 11(1), e26111124732. doi: 10.33448/rsd-v11i1.24732

Hall, C., Prayag, G., Fieger, P. & Dyason, D. (2020). Beyond panic buying: consumption displacement and COVID-19. *Journal of Service Management*, 32(1), 113-128. doi: 10.1108/JOSM-05-2020-0151

Haralambides, H. (2002). Competition, excess capacity, and the pricing of port infrastructure. International Journal of Maritime Economics 4 (4), 323-347.

Heckmann, I., Comes, T. and Nickel, S. (2015). A critical review on supply chain risk - Definition, measure and modeling. *Omega*, 52, 119-132.

Hendricks, K. & Singhal, V. (2003). The effect of supply chain glitches on shareholder wealth. *Journal of Operations Management*, 21(5), 501-522. doi: 10.1016/j.jom.2003.02.003

Henningsen, A. (2012). Estimating Censored Regression Models in R using the censReg Package. Available at: https://cran.r-project.org/web/packages/censReg/vignettes/censReg.pdf [Accessed in 13 July 2022]

Hobbs, J. (2020). Food Supply Chains During The COVID-19 Pandemic. *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*, 68(2), 171-176. doi: 10.1111/ cjag.12237.

Hove-Sibanda, P., Sibanda, K. & Pooe, D. (2017). The impact of cooperate governance on firm competitiveness and performance of small and medium enterprises in Vanderbijlpark. *Acta Commercii*, 17(1), 1-11. doi: 10.4102/ac.v17i1.446

Hu, Z. (2011). A container multimodal transportation scheduling approach based on immune affinity model for emergency relief. *Expert Systems with Applications*, 38(3), 2632-2639. doi: https://doi.org/10.1016/j.eswa.2010.08.053

Huang, C., Wang, Y., Li, X., Ren, L., Zhao, J., Hu, Y., Zhang, L., Fan, G., Xu, J., Gu, X., & Cheng, Z. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *The Lancet*, 395(10223), 497-506. doi: 10.1016/ S0140-6736(20)30183-5

Huang, X., Wang, Y., Dai, X., Luo, J. X., & Chen, J. (2020). Evaluation of port efficiency in Shanghai Port and Busan Port based on three-stage DEA model with environmental concerns. *Transport*, 35(5), 454-461. doi: 10.3846/transport.2019.11465

iContainers. (2019). What is port-to-port shipping. Available at: https://www.icontainers.com/help/what-is-port-to-port-shipping/ [Accessed in 11 May 2022]

Imboden, C. (1983). *Risikohandhabung, ein entscheidbezogenes Verfahren*. Haupt. Bern.

India Times. (2022). Congestion at Port of Rotterdam seen persisting through 2022. Available at: https://economictimes.indiatimes.com/small-biz/trade/exports/insights/congestion-at-port-of-rotterdam-seen-persisting-through-2022/ [Accessed in 12 April 2022]

Instituto Brasileiro de Geografia e Estatística (IBGE). (2022). Mapa Mudo – Brasil com divisão de estados. *Vamos Contar - IBGE nas escolas*. Available at: https://biblioteca.ibge.gov.br/visualizacao/mapas/GEBIS%20-%20RJ/map9825.pdf [Accessed 06 August 2022]

International Labour Organization (ILO). (2020). COVID-19 and World of Work: Impacts and Policy Responses. Available at: https://www.ilo.org/wcmsp5/groups/public/---dgreports/--dcomm/documents/briefingnote/wcms_738753.pdf [Accessed in 15 April 2022]

International Maritime Organization (IMO). (2022). Introduction to IMO. Available at: https://www.imo.org/en/About/Pages/Default.aspx [Accessed in 05 April 2022]

International Maritime Organization (IMO). (2022a). SOLAS XI-2 and the ISPS Code. Available at: https://www.imo.org/en/OurWork/Security/Pages/SOLAS-XI2%20ISPS%20Code.aspx#:~:text=The% 20 International%20Ship%20and%20Port%20Facility%20(ISPS)%20Code&text=Mandatory%20Part%20A%20outlines%20detailed,in%20compliance%20with%20the%20Code. [Accessed in 10 December 2022]

International Monetary Fund (IMF). (2020). Annual Report 2020 – A Year Like No Other. Available at: https://www.imf.org/external/pubs/ft/ar/2020/eng/spotlight/covid-19/ [Accessed in 17 April 2022]

International Monetary Fund (IMF). (2022). Supply Chains and Port Congestion Around the World. Available at: https://www.imf.org/en/Publications/WP/Issues/2022/03/25/Supply-Chains-and-Port-Congestion-Around-the-World-515673#:~:text=First%2C%20at%20the%20world%20level,increase%20in%20global%20travel%20times. [Accessed in 17 May 2022]

Iyengar, K., Vaishya, R., Bahl, S & Vaish, A. (2020). Impact of the Coronavirus Pandemic on Supply Chain in Healthcare. *British Journal of Healthcare Management*, 26(6), 1-4. doi: 10.12968/bjhc.2020.0047.

Janvier-James, A. (2012). A New Introduction to Supply Chains and Supply Chain Management: Definitions and Theories Perspective. *International Business Research*, 5(1), 194–207. doi:10.5539/ibr.v5n1p194

Jüttner, U. & Maklan, S. (2011). Supply chain resilience in the global financial crisis: an empirical study. *Supply Chain Management: An International Journal*, 16(4), 246-259.

Jüttner, U., Peck, H. & Christopher, M. (2003). Supply Chain Risk Management: Outlining an Agenda for Future Research. *International Journal of Logistics: Research & Applications*, 6(4), 197-210.

Kaplan, R. S. & Norton, D. P. (1992). The Balanced Scorecard - Measures that Drive Performance. Harvard Business Review. Available at: https://hbr.org/1992/01/the-balanced-scorecard-measures-that-drive-performance-2 [Accessed in 20 May 2022]

Kim, S.Y. & Marlow, P. (2001). The measurement of efficiency and effectiveness in distribution channels. Report presented at the *9th World Conference on Transport Research* (July 22-27). Seoul, South Korea.

Kleindorfer, P. & Saad, G. (2005). Managing disruption risks in supply chain. *Production and Operations Management*, 14(1), 53-68.

Kwak, D.-W., Seo, Y.-J. & Mason, R. (2017). Investigation the relationship between supply chain innovation, risk management capabilities and competitive advantage in global supply chains. *International Journal of Operations and Production Management*, 38(1), 2-21. doi: 10.1108/IJOPM-06-2015-0390

Landis, A. (2022). Biden administration appoints new ports and supply chain czar. *Spectrum News – NY1*. Available at: https://issafrica.org/iss-today/security-vs-efficiency-smart-ports-in-a-post-covid-19-era [Accessed 27 June 2022]

Langen, P. (*2015). Business development in ports. Port Management 3*. Erasmus University Rotterdam. Rotterdam.

Langley, C., Coyle, J., Gibson, B., Novack, R., & Bardi, E. (2008). *Managing Supply Chains: A Logistics Approach.* Canada: South-Western Cengage Learning.

Lee, C. & Song, D. (2017). Ocean container transport in global supply chains: Overview and research opportunities. *Transportation Research Part B*, 95, 442–474. DOI: 10.1016/j.trb.2016.05.001

Levinson, M. (2016). *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger (2nd ed)*. Princeton University Press. New Jersey. doi: 10.2307/j.ctvcszztg

Li, C., Qi, X. & Lee, C. (2015). Disruption recovery for a vessel in liner shipping. *Transportation Science* 49 (4), 900 – 921. doi: 10.1287/trsc.2015.0589

Liang, L., Cook, W. & Zhu, J. (2008). DEA models for two-stage processes: game approach and efficiency decomposition. *Naval Research Logistics*, 55, 643–653.

Liebuvienè, J. & Cˇižiu¯nienè, K. (2022). Comparative Analysis of Ports on the Eastern Baltic Sea Coast. *Logistics*, 6(1), 1-29. doi: 10.3390/logistics6010001

Lima, M. R. S. de, Milani, C. R. S., Duarte, R. de S., Albuquerque, M. R. A. de, Acácio, I. D. P., Carvalho, T. C., Medeiros, J., Novacek, N., Costa, M. G. da, Costa, H. B. M. da & Lemos, J. P. (2017). *Atlas da Política Brasileira de Defes. (1ª ed.)*. CLACSO, Buenos Aires; Latitude Sul, Rio de Janeiro. Retrieved from: https://www.researchgate.net/publication/316999884_Atlas_da_politica_brasileira_de_defesa

Lin, Y., Yan, L. & Wang, Y-M. (2019). Performance Evaluation and Investment Analysis for Container Port Sustainable Development in China: An Inverse DEA Approach. *Sustainability*, 11(17), 4617. doi: 10.3390/su11174617

Lind, M., Lehmacher, W., Hoffmann, J., Jensen, L., Notteboom, T., Rydbergh, T., Sand, P., Haraldson, S., White, P., Becha, H. & Berglund, P. (2022). *Synchronisation across maritime value chains can ease inflation*. The Loadstar Media. Kent.

Lind, M., Lehmacher, W., Hoffmann, J., Jensen, L., Notteboom, T., Rydbergh, T., Sand, P., Haraldson, S., White, R., Becha, H. & Berlund, P. (2022). Synchronisation across maritime value chains can ease inflation. *The Load Star*. Available at: https://theloadstar.com/synchronisation-across-maritime-value-chains-can-ease-inflation/ [Accessed 16 June 2022]

Lindert, M. (2022). Disruptions force manufacturers to rethink logistics outsourcing. *Supply Chain Movement*. Available at: https://www.supplychainmovement.com/disruptions-force-manufacturers-to-rethink-logistics-outsourcing/#:~:text=Supply%20chain%20disruptions%20are%20forcing,into%20other%20areas%20of%20logistics [Accessed 15 December 2022]

Linkov, I. & Palma-Oliveira, J. M. (2017). *Resilience and Risk: Methods and Application in Environment, Cyber and Social Domains (NATO Science for Peace and Security Series C: Environmental Security) (1st ed.)*. Springer, Dordrecht. doi: 10.1007/978-94-024-1123-2

Lins, M. P. E., Meza, L. A. & Antunes, C. H. (2000). *Análise envoltória de dados: e perspectivas de integração no ambiente do Apoio à Decisão*. COPPE/UFRJ, Rio de Janeiro.

Linton, T. & Vakil, B. (2020). Coronavirus Is Proving We Need More Resilient Supply Chains. *Harvard Business Review*. Available at: https://hbr.org/2020/03/coronavirus-is-proving-that-we-need-more-resilient-supply-chains [Accessed 17 April 2022]

Liu, C. (2008). Evaluating the operational efficiency of major ports in the Asia-Pacific region using data envelopment analysis. *Applied Economics*, 40(13), 1737-1743. doi: 10.1080/00036840600905126

Liu, M.L. (2020). Research on port infrastructure, port efficiency and urban trade development. In Bai, X. & Zhou, H. (eds.). *Journal of Coastal Research, Special Issue No. 115: Advances in Water Resources, Environmental Protection, and Sustainable Development*, (pp. 220-222). Florida, United States: BioOne

Liu, Z. (1995). The comparative performance of public and private enterprises: the case of British ports. *Journal of Transport Economics and Policy*, 29 (3), 263–274. Available at: https://www.jstor.org/stable/20053084 [Accessed in 24 June 2022]

Lloyd's List. (2020). One Hundred Ports - 2020. Available at: https://lloydslist.maritimeintelligence.informa.com/one-hundred-container-ports-2020/ [Accessed in 13 May 2022]

Lopez, E. (2021). Empty containers become a focal point in push to ease Los Angeles port congestion. Supply Chain Dive. Available at: https://www.supplychaindive.com/news/empty-containers-ease-congestion-port-of-los-angeles/610171/ [Accessed in 17 May 2022]

Lovell, C. A. K. (1993). Production Frontier and Productive Efficiency. In Fried, H., Lovell, C. A. K. & Schmidt, S. S. (eds), *The Measurement of Productive Efficiency* (ch. 1). New York, NY: Oxford University Press.

Madzimure, J. (2020). Supply Chain Robustness, Firm Competitiveness and Performance of South African Logistic Firms. *Eurasian Journal of Business and Management*, 8(2), 137-149. doi: 10.15604/ejbm.2020.08.02.007

Manuj, I. & Mentzer, J. (2008). Global supply chain risk management. *Journal of Business Logistics*, 29(1), 133-151.

Manuj, I. & Sahin, F. (2011). A model of supply chain and supply chain decision-making complexity. *International Journal of Physical Distribution & Logistics Management*, 41(5), 511-549.

March, J., Shapira, Z. (1987). Managerial Perspectives on Risk and Risk Taking. *Management Science*, 33(11), 1404-1418.

Martinez-Budria, E., Diaz-Armas, R., Navarro-Ibanez, M. & Ravelo-Mesa, T. (1999). A study of the efficiency of Spanish port authorities using data envelopment analysis. *International Journal of Transport Economics*, 26 (2), 237–253. Available at: https://www.jstor.org/stable/42747746 [Accessed in 24 June 2022]

Mattos, N. (2021). O que você precisa saber sobre a BR do Mar. *Agência EPBR*. Available at: https://epbr.com.br/o-que-voce-precisa-saber-sobre-a-br-do-mar/ [Accessed 20 October 2022]

Mayo, A. & Nohria, N. (2005). The Truck Driver Who Reinvented Shipping. Harvard Business School. Available at: https://hbswk.hbs.edu/item/the-truck-driver-who-reinvented-shipping [Accessed in 10 May 2022]

Medal-Bartual, A., Molinos-Senate, M. & Sala-Garrido, R. (2017). Technical Efficiency of Iberian Port Authorities by Specialization: a DEA Metafrontier Approach. *Revista Electrónica de Comunicaciones y Trabajos de ASEPUMA*, 18, 37-51. doi: 10.24309/recta.2017.18.1.03

Meepetchdee, Y. & Shah, N. (2007). Logistical network design with robustness and complex considerations. *International Journal of Physical Distribution and Logistics Management*, 37(3), 201-222. doi: 10.1108/09600030710742425

Meeusen, W. & Van der Broeck, J. (1977). Technical efficiency and dimension of the firm: same results on the use of frontier production functions. *Empirical Economics*, 2(2), 109–122.

Melnyk, S., Rodrigues, A. & Ragatz, G. (2009). Using simulation to investigate supply chain disruptions. In Zsidisin, G. & Ritchie, B. (2009). *Supply Chain Risk: A Handbook of Assessment, Management, and Performance*. International Series in Operations Research & Management Science (ISOR) 124, 103-122.

METRANS Transportation Consortium. (2016). How competition is driving change in port governance, strategic decision-making, and government policy in the United States. University of Southern California. Available at: https://www.metrans.org/assets/research/MF%201.1f_Competition%20Driving%20Change%20in%20Ports_Research%20Brief_111816.pdf [Accessed in 04 May 2022]

Metters, R.D., Frei, F.X. & Vargas, V.A. (1999). Measurement of multiple sites in service firms with data envelopment analysis. *Production and Operations Management*, 8(3), 264-281. Available at: https://www.academia.edu/21410524/Measurement_of_multiple_sites_in_service_firms_with_data_envelopment_analysis [Accessed in 08 May 2022]

Miller, K. (1992). A framework for integrated risk management in international business. *Journal of International Business Studies*, 23(2), 311–331.

MoverDB. (2022). Top 49 Biggest & Busiest Container Ports In 2022. Available at: https://moverdb.com/top-49-container-ports/ [Accessed in 13 May 2022]

Munim, Z. & Schramm, H-J. (2018). The impacts of port infrastructure and logistics performance on economic growth: the mediating role of seaborne trade. *Journal of Shipping and Trade*, 3(1), 1-19. doi: 10.1186/s41072-018-0027-0

Muñuzuri, J., Onieva, L., Escudero, A. & Cortés, P. (2016). Impacts of a Tracking and Tracing System for Containers in a Port-Based Supply Chain. *Brazilian Journal of Operations & Production Management*, 13(3), 352-359. doi: 10.14488/BJOPM.2016.v13.n3.a12

Nagurney, A. (2021). Global shortage of shipping containers highlights their importance in getting goods to Amazon warehouses, store shelves and your door in time for Christmas. The Conversation. Available at: https://theconversation.com/global-shortage-of-shipping-containers-highlights-their-importance-in-getting-goods-to-amazon-warehouses-store-shelves-and-your-door-in-time-for-christmas-168233/ [Accessed in 10 May 2022]

Nemuraitė, L. (2011). *Klaipėdos Valstybinio jūrų uosto Konkurencingumo Tyrimas*. Baigiamasis Magistro Darbas, VGTU. Vilnius.

Niérat, P. & Guerrero, D. (2019). UNCTAD maritime connectivity indicators: review, critique and proposal. *United Nations Conference on Trade and Development (UNCTAD)*. Available at: https://unctad.org/news/unctad-maritime-connectivity-indicators-review-critique-and-proposal [Accessed 27 December 2022]

Nikookar, E. & Yanadori, Y. (2022). Preparing supply chain for the next disruption beyond COVID-19: managerial antecedents of supply chain resilience. *International Journal of Operations & Production Management*, 42(1), 59-90. doi: 10.1108/IJOPM-04-2021-0272

Noritake, M. & Kimura, S. (1983). Optimum number and capacity of seaport berths. *Waterway Port Coastal and Ocean Engineering*, 109, 323–339.

Notteboom, T., Pallis, A.A. & Rodrigue, J-P. (2020). *Ports and shipping in the COVID- 19 pandemic*. Port Technology International, Issue 100. London.

Notteboom, T., Pallis, A.A. & Rodrigue, J-P. (2022). *Port Economics, Management and Policy - The Concept of Port Resilience*. Retrieved from: https://porteconomicsmanagement.org/pemp/contents/part6/port-resilience/resilience-maritime-transportation-systems/#:~:text=Restorative%20capacity.,or%20even%20above%20a%20baseline. [Accessed in 19 May 2022]

Notteboom, T., Pallis, A.A. & Rodrigue, J-P. (2022a). *Port Economics, Management and Policy -The World Bank and Port Performance*. Retrieved from: https://porteconomicsmanagement.org/pemp/contents/part6/port-performance/the-world-bank-and-port-performance-measurement/

Notteboom, T., Pallis, A.A. & Rodrigue, J-P. (2022b). *Port Economics, Management and Policy - Country and Port Level Liner Shipping Connectivity Index*. Retrieved from https://porteconomicsmanagement.org/pemp/contents/part1/ports-and-container-shipping/country-port-level-liner-shipping-connectivity-index/

Nze, I. C., & Onyemechi, C. (2018). Port congestion determinants and impacts on logistics and supply chain network of five African ports. *Journal of Sustainable Development of Transport and Logistics*, 3(1), 70-82. doi:10.14254/jsdtl.2018.3-1.7.

Oliveira, C. T. (1992). *Comércio Exterior e a Questão Portuária*. Aduaneiras. São Paulo.

Oliveira, G. F. de & Cariou, P. (2015). The impact of competition on container port (in)efficiency. *Transportation Research Part A: Policy and Practice*, 78, 124–133. doi: 10.1016/j.tra.2015.04.034

Oliveira, J., Lima, R. & Montevechi, J. (2016). Perspectives and relationships in supply chain simulation: a systematic literature review. *Simulation Modelling Practice and Theory*, 62, 166–191.

Onwuegbuchunam, D. E. (2018). Assessing Port Governance, Devolution and Terminal Performance in Nigeria. *Logistics*, 2(1), 1–16. doi: 10.3390/logistics2010006

Organisation for Economic Co-operation and Development (OECD). (2022). Ocean shipping and shipbuilding. Available at: https://www.oecd.org/ocean/topics/ocean-shipping/ [Accessed in 10 May 2022]

Organisation for Economic Co-operation and Development (OECD). (2022). Benchmarking Intermodal Freight Transport. Available at: https://www.internationaltransportforum.org/Pub/pdf/02BenchmarkingE.pdf/ [Accessed in 24 May 2022]

Osobajo, O., Koliousis, I. & McLaughlin, H. (2021). Making sense of maritime supply chain: a relationship marketing approach. *Journal of Shipping and Trade*, 6(1), 1-17. doi: 10.1186/s41072-020-00081-z

Ozanne, D. & Stolze, H. (2021). A transformative supply chain response to COVID-19. *Journal of Service Management*, 32(2), 190-202. doi: 10.1108/JOSM-05-2020-0143

Panayides, P.M., Maxoulis, C.N., Wang, T.F. & Ng, K.Y.A. (2009). A critical analysis of DEA applications to seaport economic efficiency performance. *Transport Reviews*, 29 (2), 183–206. doi: 10.1080/01441640802260354

Pérez, I., González, M. M. & Trujillo, L. (2020). Do specialisation and port size affect port efficiency? Evidence T from cargo handling service in Spanish ports. *Transportation Research Part A: Policy and Practice*, 138, 234-249. doi: 10.1016/j.tra.2020.05.022

Perni, P. H. R. de. (2019). *O Setor Portuário Brasileiro no Contexto da Defesa e Segurança Nacionais*. Curso de Altos Estudos em Defesa., Escola Superior de Guerra – Campus Brasília, Distrito Federal, Brasil. Retrieved from: https://repositorio.esg.br/bitstream/123456789/1305/1/PAULO%20Henrique%20Ribeiro%20de%20PERNI.pdf

Pfohl, H-C., Gallus, P. & Köhler, H. (2008). *Konzeption des Supply Chain Risikomanagements*. Pfohl H (ed) Sicherheit und Risikomanagement in der Supply Chain. Gestaltungsansätze und praktische Umsetzung. Deutscher Verkehrs-Verlag. Bremen.

Pfohl, H-C., Köhler, H. & Thomas, D. (2010). State of the art in supply chain risk management research: empirical and conceptual findings and a roadmap for the implementation in practice. *Logistics Research*, 2, 33–44.

Pham, T. Q. M., Park, G. K. & Choi, K-H. (2021). The efficiency analysis of world top container ports using two-stage uncertainty DEA model and FCM. *Maritime Business Review*, 6(1), 2-21. doi: 10.1108/MABR-11-2019-0052

Pournader, M., Kach, A. & Talluri, S. (2020). A Review of the Existing and Emerging Topics in the Supply Chain Risk Management Literature. *Decision Sciences*, 51(4), 867-919. doi: 10.1111/deci.12470

Puidokas, M. & Andriuškaitė, L. (2012). Klaipėdos valstybinio jūrų uosto transporto politikos analizė pozicionuojant Lietuvą kaip jūrinę valstybę. *Viešoji Politika Ir Administravimas*, 11(3), 404–419.

Ray, S. C. (2002). William W. Cooper: A legend in his own times. *Journal of Productivity Analysis*, 17, 7–12. doi:10.1023/A:1013591500194

Remko, V. (2020). Research Opportunities for a More Resilient Post-COVID-19 Supply Chain – Closing the Gap between Research Findings and Industry Practice. *International Journal of Operations & Production Management*, 40(4), 341–355.

Revilla, E. & Sáenz, M. (2011). What is the right disruption management for your supply chain? Forbes (India). Available at: www.forbesindia.com/article/ie/what-is-the-right- disruption-management-for-your-supply-chain/29412/1?utm=slidebox60129545314 [Accessed in 27 April 2022]

Revilla, E. & Saenz, M. (2017). The impact of risk management on the frequency of supply chain disruptions: A configurational approach. *International Journal of Operations & Production Management*, 37(5), 557-576. doi: 10.1108/IJOPM-03-2016-0129

Rezaei, J., Palthe, L. v. W., Tavasszy, L., Wiegmans, B. & Laan, F. v. d. (2019). Port performance measurement in the context of port choice: an MCDA approach. *Management Decision*, 57(2), 396-417. doi: 10.1108/MD-04-2018-0482

Rice, J.B. & Caniato, F. (2003). Building a secure and resilient supply network. *Supply Chain Management Review*, 7(5), 22-30.

Rickards, R. (2003). Setting benchmarks and evaluating balanced scorecards with data envelopment analysis. *Benchmarking: An International Journal*, 10(3), 226-245. doi: 10.1108/14635770310477762

Rios, L.R. & Maçada, A.C.G. (2006). Analysing the Relative Efficiency of Container Terminals of Mercosur using DEA. *International Journal of Maritime Economics*, 8(4), 331–346. doi:10.1057/palgrave.mel.9100168

Roberto, E. G., Matos, F. J. de, Gavião, L. O. & Kostin, S. (2020). *Comércio marítimo brasileiro: busca de países referência para desenvolver a navegação de cabotagem*. Curso de Altos Estudos em Defesa., Escola Superior de Guerra – Campus Brasília, Distrito Federal, Brasil. Retrieved from: https://repositorio.esg.br/handle/123456789/1486

Rodrigue, J. P. & Slack, B. (2002). Logistics and National Security. In: Majumdar, S. K. et al. (Eds.), *Science, Technology, and National Security*. (v.267, pp. 214-225). Easton, PA: Pennsylvania Academy of Science

Roll, Y. & Hayuth, Y. (1993). Port performance comparison applying data envelopment analysis (DEA). *Maritime Policy & Management*, 20(2), 153–161. doi: 10.1080/03088839300000025

Rowan, N. L. & Laffey, J. G. (2020). Challenges and Solutions for Addressing Critical Shortage of Supply Chain for Personal and Protective Equipment (PPE) Arising from Coronavirus Disease (COVID19) Pandemic – Case Study from the Republic of Ireland. *Science of The Total Environment*, 725: 138532. DOI:10.1016/j.scitotenv.2020.138532.

Rubem, A., Brandão, L., Costa, E., Angulo-Meza, L. & Mello, J. (2015). Evaluation of Operational Efficiency for Brazilian Port Terminals Specialized in Container Cargo Using Multiple Criteria Data Envelopment Analysis. Paper presented at the *Proceedings of the EURO 2015*. Glasgow, Scotland.

Scholten, K., Scott, P. & Fynes, B. (2014). Mitigation processes – antecedents for building supply chain resilience. *Supply Chain Management: An International Journal*, 19(2), 211–228. doi: 10.1108/SCM-06-2013-0191

SCM Globe. (2020). What is Supply Chain Management? Available at: https://www.scmglobe.com/what-is-supply-chain-management/ [Accessed in 20 April 2022]

Seatrade Maritime News. (2021). Port of Santos container volumes grow 19% Jan- July. Available at: https://www.seatrade-maritime.com/ports-logistics/port-santos-container-volumes-grow-19-jan-july [Accessed in 12 April 2022]

Segrini, F. S. (2017). O ISPS Code no Brasil e a sua importância para a certificação internacional do Navio e da Instalação Portuária. *Jus Navigandi*. Available at: https://jus.com.br/artigos/57330/o-isps-code-no-brasil-e-a-sua-importancia-para-a-certificacao-internacional-do-navio-e-da-instalacao-portuaria [Accessed 07 December 2022]

Simar, L. & Wilson, P. (2007). Estimation and inference in two-stage, semi-parametric models of production processes. *Journal of Econometrics*, 136 (1), 31–64. doi: 10.1016/j.jeconom.2005.07.009

Sindicato dos Operadores Portuários do Estado de São Paulo (SOPESP). (2022). Covid-19: Um olhar sobre suas consequências em logística, portos e companhias marítimas. Available at: https://www.sopesp.com.br/2020/09/25/covid-19-um-olhar-sobre-suas-consequencias-em-logistica-portos-e-companhias-maritimas/ [Accessed in 20 April 2022]

Singh, S., Kumar, R., Panchal, R. & Tiwari, M. (2021) Impact of COVID-19 on logistics systems and disruptions in food supply chain. *International Journal of Production Research*, 59(7), 1993-2008. doi: 10.1080/00207543.2020.1792000

Slack, N., Brandon-Jones, A. & Johnston, R. (2013). *Operations Management (7th ed.)*. Pearson Education. Harlow.

Smialek, J. & Swanson, A. (2022). The Era of Cheap and Plenty May Be Ending. *The New York Times*. Available at: https://www.nytimes.com/2022/05/03/business/economy/pandemic-supply-chains-inflation.html [Accessed 08 December 2022]

Smith, J. (2020). Warehouse hiring surge defies crashing U.S. jobs market. Wall Street Journal. Available at: https://www.wsj.com/articles/warehouse-hiring-surge-defies-crashing-u-s-jobs-market-11585939391?mod=hp_minor_pos15 [Accessed in 29 April 2022]

Sölvell, Ö. (2015). The Competitive Advantage of Nations 25 years — opening up new perspectives on competitiveness. *Competitiveness Review*, 25(5), 471-481. doi: 10.1108/CR-07-2015-0068

Sölvell, Ö. (2015a). *The Dynamic Firm: The Role of Technology, Strategy, Organizations, and Regions*. Oxford University Press. New York.

Statista. (2022). Container shipping - statistics & facts. Available at: https://www.statista.com/topics/1367/container-shipping/ [Accessed in 10 May 2022]

Steinbach, S. (2022). Port congestion, container shortages, and U.S. foreign trade. *Economics Letters*, 213, 110392. doi: 10.1016/j.econlet.2022.110392

Suárez-Alemán, A., Serebrisky, T. & Ponce de León, O. (2018). Port reforms in Latin America and the Caribbean: where we stand, how we got here, and what is left. *Maritime Economics and Logistics*, 20(4), 495–513. doi: 10.1057/ s41278-017-0086-4

Sun, J., Yuan, Y., Yang, R., Ji, X. & Wu, J. (2017). Performance evaluation of Chinese port enterprises under significant environmental concerns: An extended DEA-based analysis. *Transport Policy*, 60, 75-86. doi: 10.1016/j.tranpol.2017.09.001

Talley, W. K. (2007). Port performance: an economic perspective. In: Brooks, M. R. & Cullinane, K. (Eds.), *Research in Transportation Economics: Devolution, port governance and port performance* (v. 17, pp. 499–516). Amsterdam, Netherlands: Elsevier.

Talluri, S. & Sarkis, J. (2001). A computational geometry approach for benchmarking. *International Journal of Operations & Production Management*, 21(1), 210-22. doi: 10.1108/01443570110358549

The Britannica Dictionary. (2022). Port. Available at: https://www.britannica.com/dictionary/port [Accessed in 03 May 2022]

The Guardian. (2021). A record number of cargo ships are stuck outside LA. What's happening?. Available at: https://www.theguardian.com/us-news/2021/sep/22/cargo-ships-traffic-jam-los-angeles-california [Accessed in 12 April 2022]

The Guardian. (2021). Backlogged LA port struggles to implement 24/7 schedules: 'We've had very few takers'. Available at: https://www.theguardian.com/business/2021/nov/17/container-ship-traffic-jam-port-los-angeles-ease [Accessed in 12 April 2022]

The Loadstar. (2022). Congestion surges at Chinese ports amid Shanghai lockdowns and driver curbs. Available at: https://theloadstar.com/congestion-surges-at-chinese-ports-amid-shanghai-lockdowns-and-driver-curbs/ [Accessed in 12 April 2022]

Tongzon, J. & Heng, W. (2005). Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). *Transportation Research Part A: Policy and Practice*, 39, 405-424. doi:10.1016/j.tra.2005.02.001

Tongzon, J. L. (2009). Port choice and freight forwarders. *Transportation Research Part E*, 45, 186-195. doi: 10.1016/j.tre.2008.02.004

Trujillo, L., González, M. M. & Jiménez, J. L. (2013). An overview on the reform process of African ports. *Utilities Policy*, 25(1), 12-22. doi: 10.1016/j.jup.2013.01.002

Turner, H., Windle, R. & Dressner, M. (2004). North American container port productivity: 1984–1997. *Transportation Research Part E Logistics and Transportation Review*, 40(4), 339-356. doi: 10.1016/j.tre.2003.06.001

United Kingdom. (2022). National strategy for maritime security. *Secretary of State for Transport*. Available at: https://www.gov.uk/government/publications/national-maritime-security-strategy [Accessed 10 November 2022]

United Nations Conference on Trade and Development (UNCTAD). (1976). Port Performance Indicators. Available at: https://unctad.org/system/files/official-document/tdbc4d131sup1rev1_en.pdf [Accessed in 20 May 2022]

United Nations Conference on Trade and Development (UNCTAD). (2016). Port Management Series Vol. 4 – Port Performance. Available at: https://unctad.org/system/files/official-document/dtlkdb2016d1_en.pdf [Accessed in 20 May 2022]

United Nations Conference on Trade and Development (UNCTAD). (2021). Review of Maritime Transport 2021. Available at https://unctad.org/system/files/official-document/rmt2021_en_0.pdf [Accessed 14 April 2019].

United Nations Conference on Trade and Development (UNCTAD). (2020). Review of Maritime Transport 2020. Available at https://unctad.org/system/files/official-document/rmt2020_en.pdf [Accessed 14 April 2019].

United States Department of Transportation. (2021). National Port Readiness Network (NPRN). *Maritime Administration*. Available at: https://issafrica.org/iss-today/security-vs-efficiency-smart-ports-in-a-post-covid-19-era [Accessed 14 June 2022]

Valentine, V.F. & Gray, R. (2001), The measurement of port efficiency using data envelopment analysis. Paper presented at the *Proceedings of the 9th World Conference on Transport Research*. Seoul, South Korea.

Venuto, D. (2020). COVID-19 coronavirus lockdown: your panic buying is putting other kiwis at risk. The New Zealand Herald. Available at: https://www.nzherald.co.nz/business/covid-19-coronavirus-lockdown-your-panic-buying-is-putting-other-kiwis-at-risk/PT2V77SKIVLYJB3 R3Y4WEV4SRU/ [Accessed in 25 April 2022]

Wan, Y., Yuen, A. C. & Zhang, A. (2014). Effects of hinterland accessibility on US container port efficiency. *International Journal of Shipping and Transport Logistics*, 6(4), 422-440. doi: 10.1504/IJSTL.2014.062908

Wang, K., Wang, S., Zhen, L. & Qu, X. (2017). Ship type decision considering empty container repositioning and foldable containers. *Transportation Research Part E: Logistics and Transportation Review*, 108, 97-121. doi: 10.1016/j.tre.2017.10.003

Wang, T. & Cullinane, K. (2006). The efficiency of European container terminals and implications for supply chain management. *Maritime Economics and Logistics*, 8(1), 82–99.

Wanke, P. & Barros, C.P. (2016). New evidence on the determinants of efficiency at Brazilian ports: A bootstrapped DEA analysis. *International Journal of Shipping and Transport Logistics*, 8(3), 250-272. doi: 10.1504/IJSTL.2016.076240

Wanke, P.F. (2013). Physical infrastructure and shipment consolidation efficiency drivers in Brazilian ports: A two-stage network-DEA approach. *Transport Policy*, 29, 145-153.

Wanke, P.F., Barbastefano, R.G. & Hijjar, M.F. (2011). Determinants of Efficiency at Major Brazilian Port Terminals. *Transport Reviews, Taylor & Francis Journals*, 31(5), 653-677. doi: 10.1080/01441647.2010.547635

Waters, D. (2007). *Supply chain risk management. Vulnerability and resilience in logistics*. Kogan Page. London.

Weschenfelder, M. (2015). *The Brazilian port infrastructure attractiveness for private investors*. Erasmus University Rotterdam. Rotterdam.

White House. (2012). National Strategy for Global Supply Chain Security. Available at: https://obamawhitehouse.archives.gov/sites/default/files/national_strategy_for_global_supply_chain_security.pdf [Accessed in 30 April 2022]

Whitney, D. E., Luo, J. & Heller, D. A. (2014). The benefits and constraints of temporary sourcing diversification in supply chain disruption and recovery. *Journal of Purchasing and Supply Management*, 20(4), 238-250. doi: 10.1016/j.pursup.2014.06.001

Wiegmans, B. & Dekker, S. (2016). Benchmarking deep-sea port performance in the Hamburg- Le Havre range. *Benchmarking: An International Journal*, 23(1), 96 – 112. doi: 10.1108/BIJ-04-2013-0050

Wong, W. P. & Wong, K. Y. (2008). A review on benchmarking of supply chain performance measures. Benchmarking: An International Journal, 15(1), 25-51. doi: 10.1108/14635770810854335

World Bank. (2003). Port Reform Toolkit (2nd ed.) - Module 1: Framework for Port Reform. Available at: https://ppiaf.org/sites/ppiaf.org/files/documents/toolkits/Portoolkit/Toolkit/pdf/modules/01_TOOLKIT_Module1.pdf [Accessed in 04 May 2022]

World Bank. (2003a). Port Reform Toolkit (2nd ed.) - Module 3: Alternative port management structures and ownership models. Available at: https://ppiaf.org/sites/ppiaf.org/files/documents/toolkits/Portoolkit/Toolkit/pdf/modules/03_TOOLKIT_Module3.pdf [Accessed in 02 May 2022]

World Bank. (2003a). Port Reform Toolkit (2nd ed.) - Module 3: Alternative port management structures and ownership models. Available at: https://ppiaf.org/sites/ppiaf.org/files/documents/toolkits/Portoolkit/Toolkit/pdf/

World Bank. (2020). Global Economic Prospects, June 2020. Available at: https://openknowledge.worldbank.org/handle/10986/33748 [Accessed in 9 April 2022]

World Bank. (2021). The Container Port Performance Index 2020. Available at: https://www.maritimes.gr/images/PORTS/Container-Port-Performance_Index-WB-2021.pdf?_t=1620669079 [Accessed in 20 May 2022]

World Bank. (2022). The Container Port Performance Index 2021. Available at: https://thedocs.worldbank.org/en/doc/66e3aa5c3be4647addd01845ce353992-0190062022/original/Container-Port-Performance-Index-2021.pdf [Accessed in 25 May 2022]

World Economic Forum. (2012). New Models for Addressing Supply Chain and Transport Risk. Available at: http://www3.weforum.org/docs/WEF_SCT_RRN_NewModelsAddressingSupplyChainTransportRisk_IndustryAgenda_ 2012.pdf [Accessed in 30 April 2022]

World Health Organization (WHO). (2020). WHO Director-General’s Opening Remarks at the Media Briefing on COVID-19 - 11 March 2020. Available at: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020 [Accessed in 15 April 2022]

World Shipping Council. (2020). The Top 50 Container Ports. Available at: https://www.worldshipping.org/top-50-ports/ [Accessed in 13 May 2022]

Xie, Y., Liang, X., Ma, L. & Yan, H. (2017). Empty container management and coordination in intermodal transport. *European Journal of Operational Research*, 257 (1), 223-232. doi: 10.1016/j.ejor.2016.07.053

Yieldstreet. (2019). The most common types of large cargo ships, explained. Available at: https://www.yieldstreet.com/resources/article/types-of-cargo-ships/ [Accessed in 02 May 2022]

Yu, G. & Qi, X. (2004). *Disruption Management: Framework, Models and Applications*. World Scientific Publisher, New Jersey.

Yuen, A. C. L., Zhang, A. & Cheung, W. (2013). Foreign participation and competition: A way to improve the container port efficiency in China? *Transportation Research Part A: Policy and Practice*, 49, 220–231. doi: 10.1016/j.tra.2013.01.026

Yuen, K. & Thai, V. (2017). Barriers to supply chain integration in the maritime logistics industry. *Maritime Economics & Logistics*, 19(3), 551–572.

Zhang, L., Qu, S. & Dai, J. (2021). Port Capability Evaluation from the Perspective of Supply Chain. *Discrete Dynamics in Nature and Society*, 2021, 1-12. doi: 10.1155/2021/7633202

Zhang, L., Qu, S. & Dai, J. (2021). Port Capability Evaluation from the Perspective of Supply Chain. *Discrete Optimisation for Complex and Smart Transportation Systems*, 2021, 1-12. doi: 10.1155/2021/7633202

Zhu, J. (2011). Airlines performance via two-stage network DEA approach. *Journal of CENTRUM Cathedra* 4, 260–269.

Zhu, N., Zhang, D., Wang, W., Li, X., Yang, B., Song, J., Zhao, X., Huang, B., Shi, W., Lu, R., & Niu, P. (2020). A novel coronavirus from patients with pneumonia in China, 2019. *New England Journal of Medicine*, 382, 727-733. doi: 10.1056/NEJMoa2001017

Žimkus, R. (2016). *Jūrų uosto Konkurencingumo Vertinimo Modelis: Klaipėdos Valstybinio jūrų uosto Atvejis. Magistro Darbas* [Seaport Competitiveness Evaluation Model: The Case of Klaipeda State Seaport]. Kaunas University of Technology: Kaunas, Lithuania.

Zsidisin, G., Melnyk, S. & Ragatz, G. (2005). An institutional theory perspective of business continuity planning for purchasing and supply management. *International Journal of Production Research*, 43(16), 3401-3420.

Appendix A - Input, Intermediate Input and Output Variables (March 2018 to February 2019)

Ports	Total Area	Number of Berths	Warehousing Area	Shipment Frequency	Container Throughput
DP World Santos	848500	4	7000	432	590731,5
Imbituba	207000	3	8000	279	81413
Itaguai	400000	3	26180	380	353346
Itajai	180000	4	185800	461	469352
Paranagua	550000	3	485000	866	779259
Porto Chibatao	371675	4	70833	126	379806
Porto Itapoa	250000	2	250000	528	641247
Portonave	400000	3	207000	506	725182
Rio de Janeiro T1	188000	2	9600	293	143485
Rio de Janeiro T2	251000	2	20000	386	188686
Rio Grande	735000	3	20000	745	730357
Salvador	163368	3	4000	475	313429
Santos BTP	490000	3	430000	663	1295079
Santos Santos Brasil	610000	4	12000	809	1396504
Suape	400000	3	5000	448	441430
Super Terminais Manaus	115404	2	5749	194	230704
Terminal Portuario do Pecem	380000	2	16250	607	279895
Terminal Santa Clara	38520	1	2700	630	36274
Vila do Conde	87992	1	7500	540	146606
Vitoria Tvv	108000	2	15000	240	213097

Source: Elaborated by the author

Appendix B - Input, Intermediate Input and Output Variables (March 2019 to February 2020)

Ports	Total Area	Number of Berths	Warehousing Area	Shipment Frequency	Container Throughput
DP World Santos	848500	4	7000	630	722343,5
Imbituba	207000	3	8000	215	56157
Itaguai	400000	3	26180	360	242586
Itajai	180000	4	185800	363	436123
Paranagua	550000	3	485000	931	881003
Porto Chibatao	371675	4	70833	174	569113
Porto Itapoa	250000	2	250000	573	754926,5
Portonave	400000	3	207000	518	711873
Rio de Janeiro T1	188000	2	9600	299	176581
Rio de Janeiro T2	251000	2	20000	357	197754
Rio Grande	735000	3	20000	697	668870,5
Salvador	163368	3	4000	536	325902
Santos BTP	490000	3	430000	772	1579270
Santos Santos Brasil	610000	4	12000	809	1621213
Suape	400000	3	5000	479	481017
Super Terminais Manaus	115404	2	5749	174	118276
Terminal Portuario do Pecem	380000	2	16250	699	345410
Terminal Santa Clara	38520	1	2700	534	24407
Vila do Conde	87992	1	7500	640	120086
Vitoria Tvv	108000	2	15000	245	224723

Source: Elaborated by the author

Appendix C - Input, Intermediate Input and Output Variables (March 2020 to February 2021)

Ports	Total Area	Number of Berths	Warehousing Area	Shipment Frequency	Container Throughput
DP World Santos	848500	4	7000	702	825371,25
Imbituba	207000	3	8000	234	53229
Itaguai	400000	3	26180	368	224560
Itajai	180000	4	185800	405	522476
Paranagua	550000	3	485000	962	938628
Porto Chibatao	371675	4	70833	177	585074
Porto Itapoa	250000	2	250000	526	702491
Portonave	400000	3	207000	573	907367
Rio de Janeiro T1	188000	2	9600	268	177031
Rio de Janeiro T2	251000	2	20000	314	199710,75
Rio Grande	735000	3	20000	658	664539
Salvador	163368	3	4000	498	324234
Santos BTP	490000	3	430000	765	1599277
Santos Santos Brasil	610000	4	12000	737	1519820
Suape	400000	3	5000	441	473063
Super Terminais Manaus	115404	2	5749	171	117396
Terminal Portuario do Pecem	380000	2	16250	649	385402
Terminal Santa Clara	38520	1	2700	592	39323
Vila do Conde	87992	1	7500	612	120224
Vitoria Tvv	108000	2	15000	237	231172

Source: Elaborated by the author

Appendix D - Input, Intermediate Input and Output Variables (March 2021 to February 2022)

Ports	Total Area	Number of Berths	Warehousing Area	Shipment Frequency	Container Throughput
DP World Santos	848500	4	7000	658	854510,25
Imbituba	207000	3	8000	301	54586
Itaguai	400000	3	26180	339	167695
Itajai	180000	4	185800	346	487324
Paranagua	550000	3	485000	882	1056238
Porto Chibatao	371675	4	70833	165	605807
Porto Itapoa	250000	2	250000	506	785567
Portonave	400000	3	207000	619	1095906
Rio de Janeiro T1	188000	2	9600	237	158501
Rio de Janeiro T2	251000	2	20000	364	400377
Rio Grande	735000	3	20000	591	620045,5
Salvador	163368	3	4000	430	327190
Santos BTP	490000	3	430000	690	1652260
Santos Santos Brasil	610000	4	12000	729	1819536
Suape	400000	3	5000	418	443331
Super Terminais Manaus	115404	2	5749	144	129431
Terminal Portuario do Pecem	380000	2	16250	779	400129
Terminal Santa Clara	38520	1	2700	597	39139
Vila do Conde	87992	1	7500	667	105576
Vitoria Tvv	108000	2	15000	221	233831

Source: Elaborated by the author