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Evaluating Port Efficiency in North America Region using Data Envelopment Analysis.

by

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Acknowledgments

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Abstract

The performance of the port is heavily influenced by the fluctuating demand for goods. This became clear after the COVID-19 pandemic outbreak, when consumer behavior changed and their consumption of products, as opposed to services, increased in comparison to the pre-pandemic state. Port efficiency is an important metric of the overall port performance. It is a wide term that represents operational performance, especially the maximizing of outputs with the minimum amount of resources. The purpose of this thesis is to determine the efficiency levels of some of North America's busiest seaports, as there are currently no studies focusing on this particular region. Port authorities and private industries associated with the ports in this area may be interested in the outcomes of this research so that, if necessary, they can take the appropriate steps to increase efficiency. This research will be conducted using Data Envelopment Analysis (DEA) as methodology and RStudio as platform to achieve the expected results. A total of 15 seaports will be analyzed using 4 inputs and 1 output. We will focus the research on the period after pandemic, considering volumes of years 2020 and 2021. According to the study's evaluation of efficiency levels, four seaports operate at the highest degree of efficiency for both the CCR and BCC models, which are Port of Los Angeles, Port of Long Beach, Port of Manzanillo and Port of Lazaro Cardenas. For seaports that did not attain 100% efficiency, the model provides input slack values, which are the resources that are not being used effectively, and, in addition, the target values, that are the output TEUs the seaport should reach in order to achieve high efficiency.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

API	Administración Portuaria Integral (Integral Port Administration)
ATP	Altamira Terminal Portuaria (Terminal Port Altamira)
BCC	Banker, Charnes and Cooper (1984)
BNSF	Burlington Northern and Santa Fe Railway
CCR	Charnes, Cooper, and Rhodes (1978)
CRS	Constant Returns to Scale
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
GDP	Gross Domestic Product
NIT	Norfolk International Terminals
NWSA	Northwest Seaport Alliance
PMT	Portsmouth Marine Terminal
RMT	Richmond Marine Terminal
TEU	Twenty-foot Equivalent Unit
UNCTAD	United Nations Conference on Trade and Development
USA	United States of America
VIG	Virginia International Gateway
VRS	Variable Returns to Scale

Chapter 1. Introduction.

1.1 Research Background.

The importance of seaports worldwide is considerable since they act as sites of intersection for the movement of people and goods between the land and the sea. The Latin word *portus*, which means gate or getaway, is where the word port was originated. In the past, ports were developed as fishing harbors, and those that were in strategic positions have developed into commerce centers, and as a result they grew into urbanization links, many of them emerging as the first important port cities and significantly contributing to the wealth of their local economies (Rodrigue, 2020). A crucial and essential element in promoting trade are seaports. Effective ports serve as basis for commerce, and they can also improve a nation's possibilities for economic development, shaping their trade's competitiveness. Thus, port efficiency might be seen as crucial for enhancing trade facilitation.

An important metric of port performance is port efficiency; more efficient ports can reduce transportation costs and make it easier for a nation to import and export goods. Port efficiency is a broad concept that describes operational performance, primarily the maximization of outputs produced with the fewest resources possible; additionally, maritime, terminal and hinterland operations contribute all together to a port's efficiency, therefore, since the inefficiencies in one of them will affect the others, these elements are connected (Notteboom, et. al, 2022). The freight rates, dwelling times, and vessel's turnround times are factors of port efficiency.

Countries with significant volumes of maritime trade set a high priority on competition in maritime ports and port services. Because of this, ports are crucial to the operation of the global economy, and strong competition in ports has a major impact on many goods' final prices. This frequently results in the necessity of assessing port efficiency, so that those concerned are aware of what they may change if necessary.

1.2 Problem Definition.

The port's performance is greatly influenced by the varying demand for goods. This became evident after the COVID-19 pandemic outbreak started back in 2019, when consumers' behavior altered, and instead of services, their consumption of goods grew compared to the pre-pandemic situation. Global supply chains were significantly impacted by this, and some port efficiencies changed as a result of the shift in demand.

Following the onset of the pandemic, temporary trade restrictions and global shortages of supplies exposed the production tactics' weakness. As a result, producers all around the world will feel pressure to try to make items in their own nations, although doing so will raise the cost of goods. Consumers, however, will continue to demand low prices, and they might not be prepared to pay more for the same products, therefore it is clear that international trade of goods will continue. Additionally, this will enhance competition and the demand for greater efficiency in ports. Therefore, in order to take steps to improve their efficiency, it is crucial to understand the level at which they now operate. A study on the port efficiency of the major seaports in North America, including those in Mexico, the United States, and Canada, is currently lacking. This is problematic since it is necessary to do this research in order to compare results and make adjustments where needed.

1.3 Objectives of the Study.

The analysis of port efficiency in North America will concentrate on both east and west coast container terminals included those in Mexico, the United States, and Canada. Data Envelopment Analysis (DEA) is the method we will employ to obtain the study's findings while utilizing comparable variables from operational perspectives. In order to apply DEA methodology, we will use RStudio to run the model. The outputs will then be ranked in order to determine how well the examined terminals performed. We use the results to highlight the region's best and least efficient ports in order to advise activities to increase efficiency.

1.4 Research Questions.

In order to assess the situation following changes in demand driven by the COVID-19 pandemic, the study intends to determine the less and more efficient maritime ports in the North American region. Therefore, the main research question is: **Which seaports in North America including those in Mexico, the United States, and Canada, are more and less efficient, according to DEA analysis?**

We will follow a few steps so we can obtain the final outcomes. We will first identify the primary seaports in the area, concentrating particularly on the key container terminals in order to use these for the DEA analysis. We will then collect the relevant data for the chosen terminals and use them as variables for the DEA problem. Then, after analyzing the findings and ranking the seaports to understand the existing situation, we can draw conclusions and recommend steps that the less efficient ports might take.

The following sub-research questions are required to support the analysis:

- What is Port Efficiency?
- What are the main seaports in Mexico, United States and Canada?
- What is the best methodology to analyze port efficiency?
- What is DEA (Data Envelopment Analysis)?
- What are the main inputs and outputs to be analyzed for the DEA problem?

These questions will allow us to make the assessment we are attempting to make with this research, consequently we can suggest some measures for the ports with the lowest rankings.

1.5 Research Methodology.

To evaluate our research question, we will employ the Data Envelopment Analysis (DEA) approach. DEA is a non-parametric technique that measures efficiency by using homogeneous entities known as DMUs with several inputs and outputs (Zhang, 2020). Each DMU receives an efficiency score based on the facts and assumptions that were collected, and for the DMUs that rated as inefficient, some target values are indicated as being required to change these values into efficient ones (Martín-Gamboa, 2021). The CCR and BCC models, which follow the names of their authors, are the two principal DEA models.

Quantitative data from secondary sources will constitute most of the data we will use for this research. Online sources and academic papers are among the tools we will use for our data collection. Some of the information can be found directly on the websites of each container port, as well as in annual reports.

1.6 Thesis Structure.

The study is organized into five chapters, starting with Introduction, followed by Literature Review, Research Methodology, Results and Analysis and finally with Conclusions and Recommendations.

In chapter 1, Introduction, the author elaborates the context and aims of the thesis and defines the DEA technique. In addition, the research and sub-research questions are presented to indicate the direction of the investigation.

In chapter 2, Literature Review, we will discuss the definition of Efficiency, Port Efficiency and a review of the main seaports in the North American region that will be included in our research.

In chapter 3, Research Methodology, the DEA methodology is explained in more detail, including an explanation of the method and why it is appropriate for this study, the different models, the method's strengths and limitations, and an explanation of data collection.

In Chapter 4, Results and Analysis The efficiency ranking will be presented, and the result will be analyzed in detail. We will discuss the outcomes of each seaport, as well as the measures that should be attained in order to get the highest level of efficiency.

In chapter 5, "Conclusion and Recommendations," the overall conclusions of the study are presented. The chapter closes with a discussion on the limitations of the study and suggestions for future research.

Chapter 2. Literature Review.

2.1. Introduction of the Chapter.

The primary objective of this chapter is to provide a thorough explanation of the concept of efficiency. At first, we will discuss about efficiency in general and explain how it may be measured and attained. After that, we will look at efficiency related specifically to ports, the relevance of seaports in the economy of countries, and the reasons why it is essential to be aware of the level of efficiency at which a port is operating. Lastly, we will provide an overview of the main seaports in North America, including those in Canada, the United States, and Mexico. This review will contain some of the highlights of each port that will be included in our research as well as its location.

2.2 Defining Efficiency.

When speaking about efficiency in a more generic sense, the benefits that an increased level of efficiency can bring to management are clearly apparent. This is due to the fact that when the operations of a facility run more efficiently, the amount of waste produced is reduced, and as a result, this will lead to an increase in profit, which will benefit directly both the company and its stakeholders enabling the firm to make the best use of its available resources.

Efficiency refers to the maximum level of performance that employs the fewer set of inputs to create the largest quantity of outputs, this includes lowering the number of unneeded resources utilized to achieve the specific output, reducing, or eliminating waste in the operation (Banton, 2022). We could consider a business to be efficient when it is able to produce a high output while using a specific input or if it is able to produce a specific output while utilizing a lesser number of inputs. When we talk about inputs, we are referring to all the resources that are required in order to produce a certain output. These resources can include elements like time, energy, labor, physical materials, equipment, financial resources, or information. The term "output" refers to the finished products or services that are created by combining various "inputs" in order to fulfill a specific requirement stated by the consumers (oag-bvg, 2022).

Productivity and efficiency are two terms that are frequently confused with one another. In order to conduct an accurate analysis of the performance, we need to be aware of the significant differences between the two approaches. Efficiency looks at input in comparison to output, whereas productivity measures output over a period of time; when taken together, they can tell you how rapidly something can be finished, the resources that are required to get through it and whether it is worth your investment (Mulholland, 2017).

Efficiency could be measured by taking the work output and dividing it by the inputs. Work output indicates the quantity of usable work that has been completed without taking into account any waste or damaged products. Either a ratio or a percentage can be used to express it. If you want to talk about efficiency in terms of a percentage, you should only multiply the ratio by 100 (Banton, 2022).

Without a doubt, Farrell's work served as a foundation for the definition of efficiency and its computation. His work inspired additional research about methods on how to measure efficiency. There are two elements that make up a company's total or economic efficiency. The first one is known as technical efficiency, which is a company's ability to produce as much output as possible from a given set of inputs. And secondly, allocative efficiency, which is a company's ability to select an optimal distribution of inputs at a given output price level (Farrell, 1957). With the exception of technical efficiency, which has been consistent over time, academic research has changed the terminology than those introduced by Farrell. Therefore, price efficiency is now called as allocative efficiency and global efficiency is now called as economic efficiency, but despite the change in terminology, the Farrell measure is the most frequently accepted and utilized (Trujillo & González, 2007).

2.3 Port Efficiency

Discussing more about seaports, we can say that despite the significant advances in maritime transport technology, the purpose of ports and the functions they provide have largely remained the same. A port is a location of interaction between land and maritime space, and it can be thought of as either a transit region or a doorway through which products and people flow from and to the sea, moreover, it is a place where various modes of transportation connect (Notteboom et al., 2020). Ports also have a geographical variation in terms of the places used for port activities, which might range from rivers to bays to offshore sites, and even while the name port may seem general, it actually reflects a large diversity of sizes and purposes (Notteboom et al., 2020).

Ports are seen as economic catalysts for the zones they serve from both an economic and public policy point of view; shipping ports play an essential role in facilitating trade and increasing the competitiveness of a region / country by providing connections that are cost-effective, reliable, and common networks to both maritime and hinterland markets; they also support trade flows and the ecosystem of activities that are related to those flows (Notteboom et al., 2020).

Given the fact that numerous activities and a diverse range of players take place within a port, it is challenging to analyze ports as if they are a single, homogenous entity; ports are extremely complicated organizations; in addition, port activities and services are distinct from one another in a number of other respects, including the nature of the operations that are carried out, the objectives that are pursued, the level of competitiveness in which they take place, and the level of regulation that they are subject to. Therefore, conducting a study into a specific activity is highly recommended (Trujillo & González, 2007).

Even when we focus on a particular activity, there is still room for variety; for example, a port not only provides services to ships, but also to passengers and freight. In addition, the cargo cannot be thought of as a homogenous good because different kinds of commodities call for different kinds of loading and unloading equipment, for example, bulk freight requires pipe systems, whereas container cargo is loaded using specialized cranes; therefore, it is frequently beneficial, from the perspective of economic and business policy, to conduct an analysis of specific factors that constitute the context in which the firms develop their operations and affect the firms' efficiency (Trujillo & González, 2005).

2.4 Container Ports in North America: An Overview.

Ports, in addition to their role in the handling of essential goods for the economy, also play an essential part in the acceleration of economic growth, the creation of large numbers of jobs, and the generation of important sources of revenue for state and national governments in North

America; the size of a port and the amount of cargo that it processes determines the contribution that it makes to the economy (Shipa Freight, 2020).

A country's proximity to a seaport affects its economy and transportation system. For that reason, the location of a country's seaports can have significant implications for that country's development. Because of these factors, it is very necessary to be aware of the level of efficiency that they have at the present in order for them to be able to take action in the event that there are low levels of efficiency. To have a better understanding of some of the busiest ports in North America, we will examine them in this section.

2.4.1 Canada

Canada's ports contribute significantly to the country's economy. Canada is one of the leading locations for aerial and maritime trade. This country in North America extends from the Atlantic to the Pacific and reaching north towards the Arctic Ocean. The country of Canada is home to more than 550 port facilities. Seventeen of them are Canada Port Authorities due to their local and international importance. Ports have a multiplier effect on area economies because regional businesses that depend on ports to transport their goods to market and build their operations are more likely to see economic growth. Whether they are located on land immediately adjacent to the port or on a large distant, local industries benefit from the facilitation provided by ports. (Government of Canada, n. d.).

The following map will indicate the four Canadian ports at which we will conduct our research.

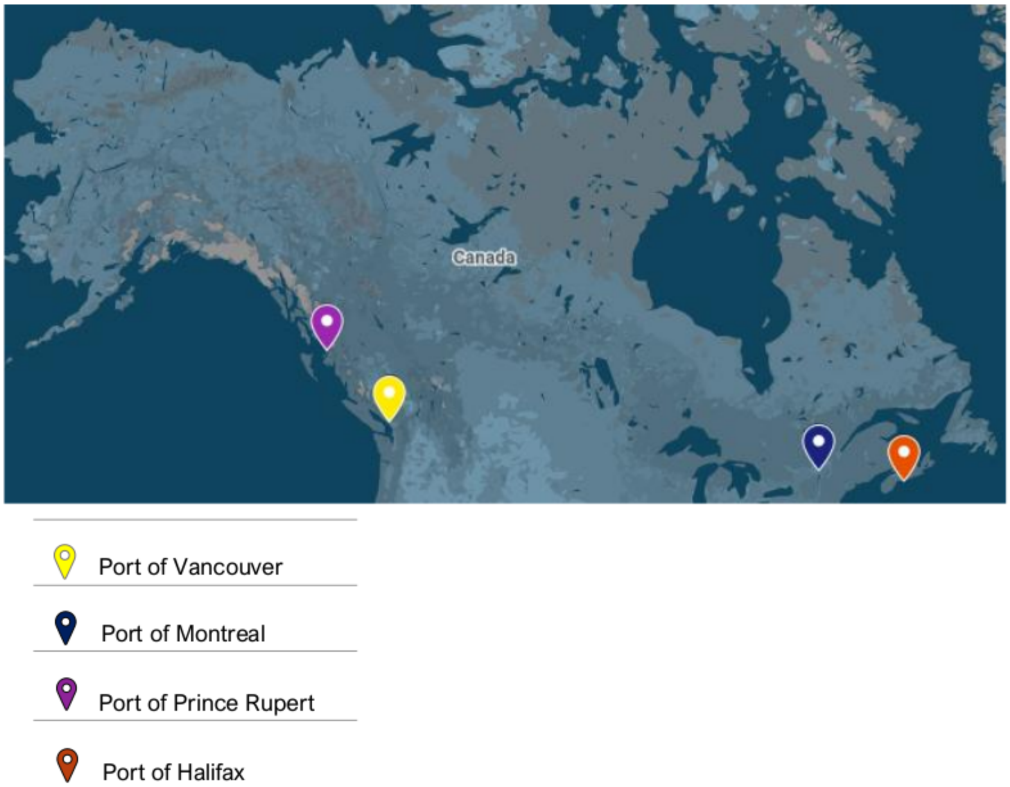


Figure 1. Canadian port locations.
Source: Own elaboration from google earth image.

Port of Vancouver. The Port of Vancouver is the largest port in Canada and one of the largest in North America and is strategically located on the west coast of America. It is situated on the southwestern coast of British Columbia. It covers from Roberts Bank and the Fraser River all the way up and includes Burrard Inlet. In terms of its physical dimensions, the Port of Vancouver covers more than 16,000 hectares of water, more than 1,500 hectares of land, hundreds of kilometers of shoreline and it is bordered on all sides by sixteen municipalities (Port of Vancouver, 2022).

The port, which is home to 29 main terminals, is equipped to handle the widest variety of cargo in all North America, including containers, bulk cargo, liquid bulk, vehicles, and cruise ships. It serves as the country's gateway to more than 170 trading economies throughout the world. Port activities in Canada are responsible for maintaining 115,300 employments, $7 billion in earnings, and $11.9

billion in GDP. The most common means of transporting freight are the truck and rail systems and currently it is expanding capacity of container trucks and railroads. (Port of Vancouver, 2022).

Port of Montreal. Montreal is the second largest city in Canada and the capital of the province of Quebec. Its port city is one of Canada's leading ports, handling more than 100 million tons of cargo annually. The port's capacity to handle freight makes it an attractive location for businesses and trade organizations to expand their operations. It is found on the Saint Lawrence Seaway, and it covers 1,600 kilometers inland from the Atlantic Ocean. It serves a wide variety of industries and type of cargo, and it is the largest port in Eastern Canada (Port of Montreal, 2022).

Port of Prince Rupert. The Port of Prince Rupert is located in the North Coast of British Columbia in Canada, and it is operated by Prince Rupert Port Authority. It covers around 20 kilometers of shoreline and more than 667 thousand hectares. After the Port of Vancouver and the Port of Montreal, the Port of Prince Rupert is the third largest seaport in Canada in terms of the volume of containers and the amount of cargo. It is 500 nautical miles closer to Asia than any other port in the Pacific Northwest, making the Port of Prince Rupert the most convenient entry point to Asia from the west coast of North America. The natural harbor of Prince Rupert is the deepest in all of North America, and the port is free of ice during the entire year, facilitating handling of large vessels. (Rupert Port, 2022).

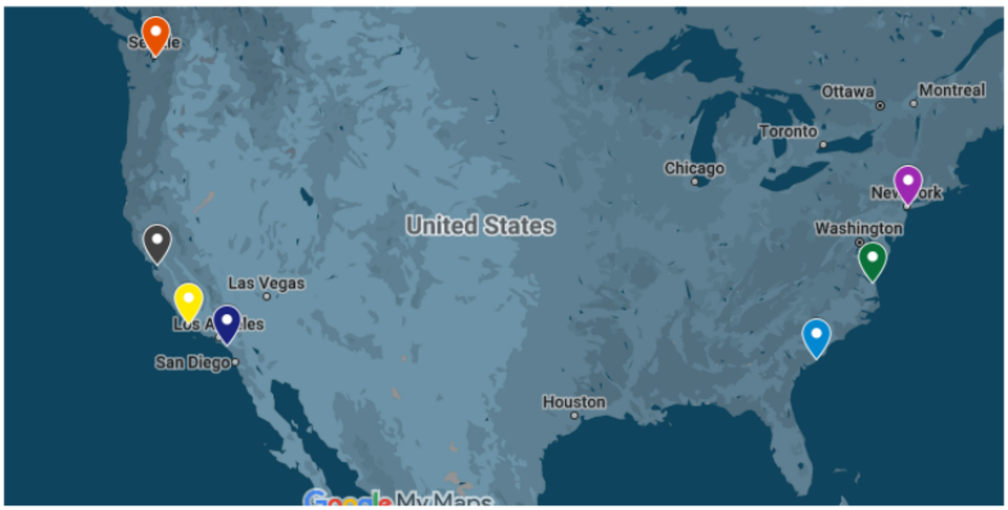
Port of Halifax. The Port of Halifax is located in Halifax, Nova Scotia on the East Coast of Canada. The cumulative effect of the Port of Halifax in 2021 resulted in an increase of economic output of $4.37 billion. This level of activity had direct and indirect positive impacts of over 22,400 jobs, 2.22 billion in GDP, and 1.42 billion in labor income. The Port of Halifax is serviced by some of the world's largest shipping lines, which creates connections to more than 150 countries worldwide (Port of Halifax, 2022).

2.4.2. United States

The economy of United States and its network of multimodal transportation are both significantly impacted by seaports located in the country. Roughly 95 percent of the cargo that enters the

United States arrives on ships, and it counts with over 360 commercial ports that facilitate the movement of this cargo to its final destinations in the various communities. Additionally, ports are an important resource for both the nation's security and its disaster response efforts. The ports of the United States serve as entry points for both domestic and international commerce. Over 99 percent of the total volume and 65 percent of the total value of the nation's international cargo is processed through seaports in the United States. These numbers are noteworthy when placed in context with the fact that the value of all foreign trade amounts for close to 30 percent of the Gross Domestic Product of the United States (GDP). The number of ships calling at U.S. seaports is at an all-time high, and the ships themselves are growing larger in order to satisfy the growing demands of consumers (EPA, 2022).

The following map shows the seven different seaports that will be included as part of our study.



Port of Los Angeles

Port of Long Beach

Port of New York and New Jersey

Northwest Seaport Alliance (NWSA)

Port of Virginia

Figure 2. Location of ports in United States.
Source: Own elaboration from google earth image.

Port of Los Angeles. The port of Los Angeles handles over 200 million tons of cargo annually. It is located on the coast in southern California and has access to deep water ports. It serves as a gateway for goods coming from Asia, Australia, Africa, and South America to North America. It has direct links with China, Australia, South Africa, and India through their respective terminals. Goods are moved to and from different parts of the country through terminals located at the port. It is the major container port in North America, and it has maintained its title as number one for more than twenty years with record levels for container - based trade. The Port of Los Angeles moved a record of 10.7 million TEUs in 2021, making it the busiest calendar year in its history. The port operates an effective and environmentally responsible supply chain, implementing modern technologies to enhance the reliability of the movement of cargo throughout international maritime trade (Port of Los Angeles, 2022).

The Port extends along 69 kilometers of coastline, which includes more than 3,000 hectares of land and sea. The Port of Los Angeles manages billions of dollars' worth of cargo on an annual basis through its passenger and cargo terminals. These terminals include container, cruise, breakbulk, liquid, and dry bulk, and warehouse facilities. The Port of Los Angeles handles a wide variety of commodities. The Port is an essential economic engine on a local and national scale, and it plays an important role in the creation of jobs, businesses, and tourist destinations in Southern California. Only in the state of California are there close to one million employment that are connected to the trade that comes via the Port of Los Angeles (Port of Los Angeles, 2022).

Port of Long Beach. The Port of Long Beach is located in the West coast of America. It is next to Port of Los Angeles, and it specializes in container traffic. It is the second busiest seaport in the country, and it carries trade with an annual value of $170 billion. Additionally, it is responsible for supporting 2.6 million jobs across the country. The Port of Long Beach is among the few ports in the United States that is able to accommodate the largest vessels in operation today. It provides services to 175 shipping lines and has connections to 217 shipping ports located all over the world (Port of Long Beach, 2022).

Port of New York and New Jersey. This is the largest container port in the United States East Coast, and it is the third busiest in the whole country. It can handle any sort of cargo and it is able to accommodate the largest vessels in the market. The natural harbor of New York is one of the largest in the world (Port Authority NY NJ, 2022).

Northwest Seaport Alliance (NWSA). Both the Port of Seattle and the Port of Tacoma are active partners in the Northwest Seaport Alliance, which serves as a maritime freight operating partnership. It is able to manage containers, breakbulk, vehicle, and some bulk terminals in both Seattle and Tacoma terminals. It provides access to the West Coast region that contains the second-largest concentration of distribution centers. More than 58,000 jobs are supported by international and domestic trade, which contributes about $12.4 billion in economic output, generates more than $4 billion in labor income, and creates around $136 million in state and municipal taxes (NW Seaport Alliance, 2022).

Port of Virginia. It is located in Hampton Roads, Virginia, in the East side of United States. An economic impact study on the port activity across our six terminals was carried out by the Mason School of Business at the College of William & Mary. This study found that port activity is responsible for the creation of 390,000 jobs in Virginia, which accounts for nearly ten percent of the state's citizen workers. These occupations result in annual pay of $23 billion and tax revenue of $2.1 billion for state and local governments. The Port of Virginia has an excellent location, in the Mid-Atlantic region. It is the longest multimodal rail port on the East Coast, with service to 19 inland locations, and it provides direct access to Interstate highways from all of its terminals (Port of Virginia, 2022).

Port of Oakland. Since its establishment, the Oakland Seaport has been Northern California's primary ocean gateway for the transport of containerized goods across international borders. It serves a local market of over 14.5 million consumers and half of the population of the United States is able to be reached by train. Since the railroad facilities of Union Pacific and Burlington

Northern and Santa Fe Railway (BNSF) are positioned next to the core of the maritime terminal region, they make it possible for goods to flow between the port terminals and the multimodal rail systems in a consistent and effective manner (Oakland Seaport, 2022).

South Carolina Ports. South Carolina ports are located in the East Coast of United States, they act as a vital economic engine for the Southeast region by ensuring the effective transportation of goods between South Carolina and worldwide markets. Port operations are responsible for producing one out of every ten jobs in South Carolina and have an annual economic impact of $63.4 billion in the state (South Carolina Ports, 2022).

2.4.3. Mexico

Along its 11,500 kilometers of coastline, Mexico has 117 ports and terminals that are fully operational. There are 16 major ports that handle the majority of the 67% of all cargo that is carried. In accordance with the National Development Plan (1989–1994), Integrated Port Administrations, often abbreviated as APIs, were formed with the purpose of assuming control over the management of port facilities. There are APIs that are owned by the federal government, by states, and by private companies. They have been designed with the purpose of encouraging industry investment, consolidating services, and producing new commercial prospects. At the moment, Mexico is relying on the services of almost 2,500 organizations that manage with exports and imports. Statistics demonstrate that the transportation industry in Mexico is headed in the right direction, as the sector contributed 1,162,121 million Mexican pesos to the country's gross domestic product (1,046 billion US Dollar) (Ports Report Mexico, 2018).

The four different seaports that will be included as part of the research are shown in the following map.

Figure 3. Mexican port locations.
Source: Own elaboration from google earth image.

Port of Manzanillo. The Port of Manzanillo is located at the West coast of Mexico in Colima. It is one of the largest ports in Mexico. The distribution of cargo that it usually handles is as follows: containers (48%), bulk (26%), oil or chemical tankers (9%) and general cargo (3%). The longest ship that are known to have entered this harbor measured 369 meters in length. (Marine Traffic, 2022).

Port of Lazaro Cárdenas. This port is the deepest port in Mexico and its location among the major shipping routes on the Pacific Coast connecting Asia and America gives it an advantageous strategic position. Lazaro Cárdenas runs the busiest customs operation in Mexico, which has more than 60 positions for the process of clearing cargo. The customs clearance procedure at this port is often completed two to three days sooner than at other ports like the port of Manzanillo. Its APM container terminal makes use of ship-to-shore cranes that have a reach of 72 meters, making them the largest in all Latin America (APM Terminals, 2022).

Port of Altamira. The Port of Altamira is situated on the shore of the Gulf of Mexico, in the state of Tamaulipas, just a short distance to the north of the city of Tampico. Convenient land and rail links connect Altamira directly to the northern and central regions of the country, including such major cities as Monterrey, Saltillo, Guadalajara, and Mexico City. The Port of Altamira, which provides services to shippers in a diverse range of industries, also provides sea links to over 125 ports located all over the world through a variety of shipping lines that are capable of handling regular as well as containerized goods (Joc, 2022).

Port of Veracruz. It is located in the Gulf of Mexico in the state of Veracruz in south-central Mexico. The port serves as the primary economic driver for the city. Additionally, it is a significant port for fishing, and both recreational fishing and other water sports are common (World Port Source, 2022).

2.5 Conclusions of the Chapter

In this chapter, we could get a better idea of what efficiency is in a more generic sense, as well as how it is applied to seaports. Also, the necessity of determining the efficiency of a seaport and how it might influence the economic climate of a country was discussed. Additionally, we could look over an overview of the ports that will be included into our research, reviewing some of the main achievements, highlights, and location of each of them.

Chapter 3. Research Methodology.

3.1 Introduction of the Chapter.

The purpose of this chapter is to provide an explanation of the approach of research that we will be using for our study, which is known as Data Envelopment Analysis (DEA). To begin, we will provide an overview of the DEA methodology, which will include an explanation of how it was initially developed, how it operates, and the different models that may be used. Then, we will discuss some of the strengths and limitations of DEA methodology and finally, the following section, entitled "Data Collection," will provide the detail data that we will need for our study. In this section we will discuss what criteria was taken into consideration for the selection of seaports, as well as what inputs and outputs we will use.

3.2 Data Envelopment Analysis (DEA) Methodology.

Data Envelopment Analysis (DEA) is one of most widespread non-parametric techniques for measuring efficiency with numerous inputs and outputs configurations. This is the most popular method for estimating frontiers in studies of efficiency across all economic activities. It is a technique of mathematical programming that was developed to make more generic the Farrell (1957) technical efficiency measure that included a single input and a single output and making possible to use multiple inputs and multiple outputs; this could be possible by establishing a relative efficiency measure as the ratio of one virtual input and one virtual output (Dea zone, 2011).

The DEA approach was initially introduced on a thesis presentation written by Rhodes that was supervised by Charnes and Cooper back in 1978, which ultimately resulted in model CCR. This was subsequently followed by the BCC model, which was presented by Banker, Charnes, and Cooper in 1984. Since it was first presented, there has been numerous applications of DEA involving the assessment of the efficiency of firms such as education institutions including schools, universities and colleges, hospitals, post offices, banks, and courts (Tongzon et al., 2004).

Data Envelopment Analysis is a method for evaluating the efficiency level of homogeneous Decision Making Units (DMU). These DMUs, which may be interpreted as the ports in our scenario, take specific inputs into account in order to generate specific outputs; DEA assists in the identification of those units that perform efficiently, provides an efficiency score to units that are not operating efficiently, and calculates efficient targets for each DMU (Lozano et al., 2010).

As Cooper et al. explained in 1978, the inputs and outputs that are similar in the decision making units (DMUs) can be numerous and they can have different formats; the concept ‘program’ is referred to as the set of DMUs, and 'relative efficiency' can be determined by the reference of making 'rankings' of the results obtained from various DMUs in the same program, taking into account that there may be different amounts of inputs (Charnes et al., 1978).

In terms of the perspective of the model, there are three distinct variants: input-oriented models, output-oriented models, and non-oriented models; if we have an input-oriented model, it indicates that an inefficient unit can become efficient by lowering the amount of inputs it receives while keeping the level of outputs it gives at least the same; in contrast, in a model that is focused on outputs, the transformation of the DMU into an efficient unit is accomplished by increasing the number of outputs while maintaining the same level of inputs; and finally, a non-oriented model, also known as a mixed model, seeks to achieve both a rise in outputs and a fall in inputs (Martín-Gamboa & Iribarren, 2021, as cited in Cooper et al., 2007).

The efficiency can be expressed as a percentage by multiplying by 100 and is calculated by dividing the amount of energy that is output by the amount of energy that is input. In a similar manner, it is argued that any ideal process has an efficiency of one hundred percent.

The following is a mathematical description by Andenoworih (2010) of a basic statement of efficiency assessment based on a single output and a single input:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \tag{1}$$

To get the expression that describes the situation when there are many inputs and various outputs, we get the weighted measures, and it is illustrated as follows:

$$\text{Efficiency} = \frac{\text{Weighted Output}}{\text{Weighted Input}} \tag{2}$$

DEA is divided into two primary models: the CCR and the BCC. The BCC was proposed by Banker, Charnes and Cooper (1984) and it is an extension of the CCR suggested by Rhodes, Charnes and Cooper (1978) with the difference that BCC takes into consideration the variable returns to scale (VRS) circumstances.

According to Rhodes, Charnes and Cooper (1978) CCR model is based on the assumption that production frontiers follow constant returns to scale (CRS), this means that this premise demonstrates that any increment in one input results in a proportional increment in one output, or otherwise, a decrease in one input should be reflected in a proportional decrease in one output.

As explained by Cooper et al. (2011), we can assume that in a CCR model, also known as the CRS (Constant Returns to Scale) model, we have *n* DMUs to be analyzed, and each of these DMUs employ various amounts of *m* inputs to produce *s* different outputs; having that DMU_j consumes x_{ij} of input *i* and produces y_{rj} of output *r*. We will assume a non-negativity constraint having that $x_{ij} \geq 0$, and $y_{rj} \geq 0$, this means that at a minimum, one positive input value and one positive output value are present in each DMU. Now, the level of relative efficiency can be determined by calculating the ratio of outputs to inputs. Then, a single virtual input and a single virtual output is evaluated for each DMU; the ratio between these single virtual input and output gives a certain measure of efficiency and this ratio is aimed to be maximized to form the objective function as follows:

$$\max h_o(u,v) = \Sigma_r u_r y_{ro} / \Sigma_i v_i x_{io} \tag{3}$$

where variables u_r and v_i, and y_{ro} and x_{io} are the output and input measures respectively and DMU_O is the DMU that is being analyzed. Considering the corresponding constraints, the complete mathematical problem would be as follows:

$$\max h_o(u,v) = \Sigma_r u_r y_{ro} / \Sigma_i v_i x_{io}$$

subject to,

$\Sigma_r u_r y_{ro} / \Sigma_i v_i x_{io} \leq 1; \;\; for\ j = 1, \ldots, n$

$u_r, v_i \geq 0; \;\; for\ all\ i\ and\ r$

The ratio form presented earlier results in an infinite number of possible solutions; therefore, an adjustment is implemented resulting in a change from (*u, v*) to (*μ, v*), and getting the following function, also recognized as multiplier form:

$$\max z = \sum_{r=1}^{s} \mu_r\, y_{ro} \qquad (4)$$

subject to,

$$\sum_{r=1}^{s} \mu_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \leq 0$$

$$\sum_{i=1}^{m} v_i\, x_{io} = 1$$

$$\mu_r, v_i \geq 0$$

And the linear programming dual form, also known as “Farrel problem” is as follows:

$$\Theta^* = min\ \Theta \qquad (5)$$

subject to,

$$\sum_{j=1}^{n} x_{ij}\, \lambda_j \leq \Theta x_{io}\,;\ \mathrm{i} = 1, 2, \ldots, \mathrm{m};$$

$$\sum_{j=1}^{n} y_{rj}\, \lambda_j \geq y_{ro}\,;\ \mathrm{r} = 1, 2, \ldots, \mathrm{s};$$

$$\lambda_j \geq 0\,; j = 1, 2, \ldots n.$$

Where λ is a constant vector and θ^* is the optimal solution that reach an efficiency rate for a particular DMU. When $\theta^* < 1$ means inefficiency and when DMUs are showing $\theta^* = 1$, means that these points are within boundary.

Still referring to Cooper's work, Cooper et al. (2011), only adding a new constraint $\sum_{j=1}^{n} \lambda_j = 1$, we get BCC model, also known as VRS (Variable Returns to Scale) model, which allows the assessment that some DMUs are working on increased, constant, or decreased returns to scale. This model takes into account the idea that an increase in inputs does not always result in an increase in outputs that is proportionate across all operational scales, being able to analyze in the same study DMU's with diverse scales. Considering this difference, due to the added constraint, the scores using CCR model will be usually lower than BCC model. This is attributable to the fact that the BCC model has more flexibility than the CCR model.

As Theodoris & Anwar (2011) describe, the scale efficiency measure, also known as SE, can be determined from the technical efficiencies with constant returns to scale and variable returns to scale, using the following equation:

$$SE = \frac{TE^{CRS}}{TE^{VRS}} \tag{6}$$

where a value of SE = 1 means constant returns to scale, and SE < 1 suggests scale inefficiency, and this scale inefficiency can either be caused by decreasing or increasing returns to scale.

The DEA model has also two types of orientation based on inputs and outputs. The input-oriented approach advises reducing the number of inputs used but maintaining the same level of outputs. On the other hand, the output-oriented approach advises an increase in outputs maintaining the same level of inputs (Basavaraj, 2021).

3.3 Strengths and Limitations of DEA Model.

The most common method for determining efficiency levels in a wide range of industries is Data Envelopment Analysis. This method, like many of the other methodologies, has some strengths over other approaches, but it also has some weaknesses in terms of its applicability. Some of these strengths and limitations will be described in this section.

Demirel (2009) has provided a concise overview of this topic related to ports, stating that one of the advantages of this model is that DEA makes it possible to evaluate efficiency using numerous inputs and numerous outputs as evaluation metrics; additionally, instead of using measures of central tendency, the DEA generates an efficient frontier that is based on the units that have been observed; another advantage is that it is not essential to have a prior knowledge of the production function that will be performed.

Some of the limitations of this model include that, due to the fact that DEA is a deterministic method, it does not take into consideration the potential effects that measurement error and other types of noise in the data may have; the premise that efficiency measure and the efficient frontier are both based on best observed values has also been questioned, this is because the scores that are obtained are not absolute values for efficiency; rather, they vary according to the data set. A DMU's DEA score indicates its relative efficiency in comparison to the other DMUs' results in the test. Another limitation that can be considered is that DEA methodology requires to equal inputs and outputs for all DMUs in the study, this is called as homogeneity requirement for the analysis (Demirel, 2009).

Isotonicity is another condition of DEA method, and it states that the output cannot reduce even if the input does. An additional drawback that we are able to point out is the fact that it is recommended that the number of DMUs be at least twice as high as the total number of variables (input and output) in order to achieve the best possible outcomes and obtain the best results. As a consequence, the majority of DEA studies have a very restricted scope regarding the inputs and outputs that they examine. DEA method is also lacking in its ability to identify the factors that contribute to the inefficiency, this means that the model does not provide a clear explanation of the inefficiency's root causes (Demirel, 2009).

Examining other approaches that are comparable, the Data Envelopment Analysis (DEA) and the Stochastic Frontier Analysis (SFA) are currently the two most often used approaches to measuring efficiency. The primary distinction between these two approaches is that the DEA is a non-parametric method while the SFA is a parametric one.

The Stochastic Frontier Analysis (SFA) is a parametric model that is driven by the assumption that no economic actor can surpass the optimal frontier and deviations from this edge imply individual inefficiencies. This concept has been put into practice by defining a regression model that is distinguished by an error term. This term attempts to capture measurement error or any other noise to represent inefficiency. The inferences that can be drawn about frontier parameters and inefficiency are the primary focus of this research (Belotti et al., 2013).

These two methodologies were created in order to estimate the frontier and quantify efficiency. The stochastic frontier can be described as the econometric approach, and Data Envelopment Analysis as a linear programming technique. The primary distinction between these two approaches, which is the root of their respective advantages and drawbacks, are basically the next two features. First, since SFA is stochastic, it can differentiate the noise from the inefficiency effects, in contrast, the linear programming DEA is not stochastic and addresses both the inefficiencies and the noise simultaneously. Secondly, the econometric method is parametric, which means that it combines the impacts of a poor functional specification, including technology and inefficiencies, as being equivalent to inefficiency, whereas, the linear programming, even that it is sensitive to returns to scale, it is less vulnerable to this kind of errors because it is a non-parametric method. Therefore, the primary benefits of using the linear programming method include the fact that it does not impose any functional shape on the data and that it is simple to manage several output processes, on the other hand, some of its drawbacks would include that the estimated frontier and, thus, the measure of efficiency might become corrupted if there is random noise. (Trujillo & González, 2007).

A summary of the main characteristics of both approaches can be easily illustrated in the following table made by Trujillo & Gonzales (2007).

DEA	**Stochastic Frontier**
Non-parametric approach	Parametric approach
Deterministic approach	Stochastic approach
Does not consider random noise	Considers random noise

Does not allow statistical hypothesis to be contrasted	Allows statistical hypothesis to be contrasted
Does not carry out assumptions on the distribution of the inefficiency term	Carries out assumptions on the distribution of the inefficiency term
Does not include error term	Includes a compound error term: one of one side and the other symmetrical (two queues)
Does not require specifying a functional form	Requires specifying a functional form
Sensitive to the number of variables, measurement errors and outliers	Can confuse inefficiency with a bad specification of the model
Estimation method: Mathematical programming	Estimation method: Econometric

Table 1. Main Features of DEA and Stochastic Frontier Analysis.
Source: Trujillo & Gonzales (2007). Efficiency measurement in the port industry: A survey of the empirical evidence.

3.4 Data Collection

The data used to run the DEA model is presented in this section. The periods of 2020 and 2021 are the focal point of our research since it is within this time frame that we will be able to examine the impact on the change in the amount of cargo that was derived from the COVID-19 pandemic. In addition to this, we have data from the years 2017 and 2018 to compare the efficiencies that existed before to the pandemic for the purpose of having a point of reference. Our analysis will primarily rely on secondary data acquired from the official websites of each convenience port.

3.4.1 Selection of Seaports

Because our study is focused on the North American region, we have chosen some of the busiest ports in each country (Canada, the United States, and Mexico), and within these ports, we analyzed only the container terminals. This is because one of the characteristics of the DEA model that we need to meet is homogeneity. Therefore, it is required to compare exclusively container terminals.

The list of seaports that are taken into consideration in this study can be found in the following table, organized by country. In total, we will consider 15 seaports. For the aim of our research, these will act as our decision-making units (DMUs).

Country	Seaport
Canada	Port of Vancouver
	Port of Montreal
	Port of Prince Rupert
	Port of Halifax
United States	Port of Los Angeles
	Port of Long Beach
	Port of New York and New Jersey
	Port of Savannah
	Northwest Seaport Alliance (NWSA)
	Port of Virginia
	Port of Oakland
	South Carolina Ports
Mexico	Port of Manzanillo
	Port of Lazaro Cardenas
	Port of Altamira
	Port of Veracruz

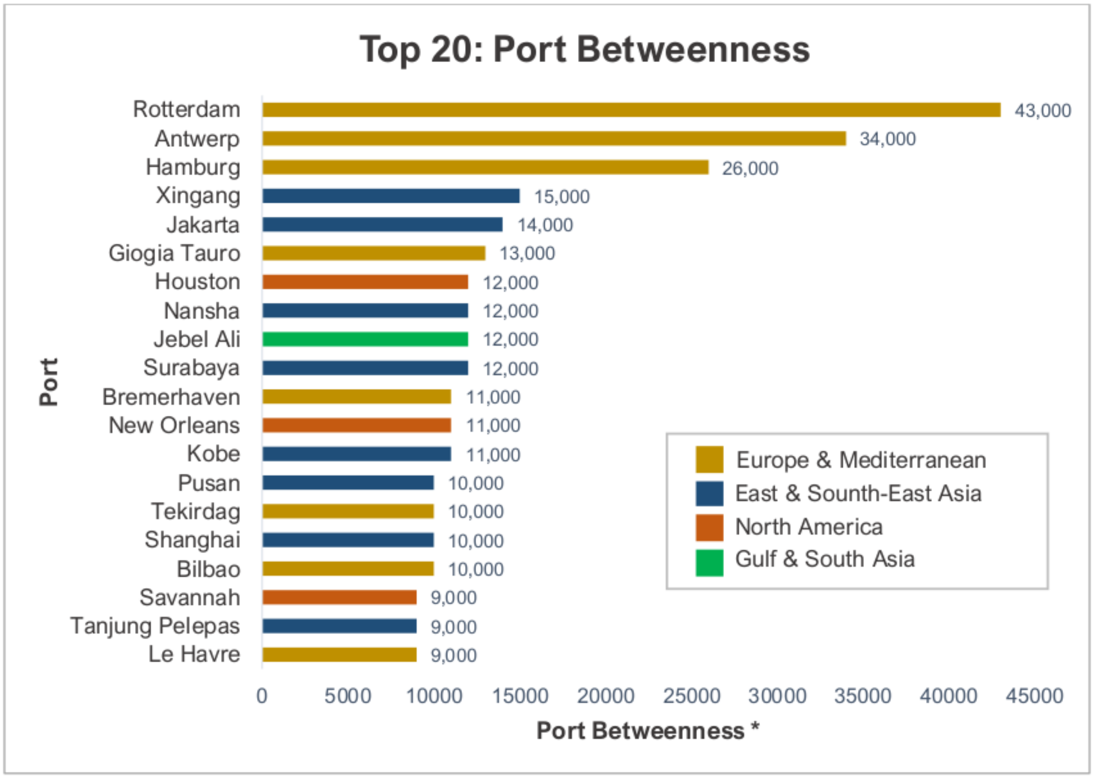
Table 2. List of Seaports considered in DEA model.
Source: Own elaboration.

The Annex 1 offers the detailed list of container terminals that were considered for the analysis by each individual seaport.

In order to fulfill the homogeneity condition of the DEA model, we also take into consideration the transshipment rate of the container ports selected for our analysis. In the case of Canada, the actual transshipment ratio is quite low. This is due to the fact that the restrictions that are now in place regarding Canadian customs are often complex and cause delays in transfer between locations of origin and the destination. Because of these delays, there is now a competitive base for direct port-to-port shipping, for instance Antwerp to Cleveland, which avoids Canadian ports like Halifax and Montreal. There are proposals to enhance container transshipment ports in Eastern Canada, such as the Port of Halifax, where the Canadian government is developing advanced cargo inspection equipment in order to make the customs procedure go more rapidly. However, at the present moment, these regulations keep the transshipment ratios in these areas relatively low (Valentine, 2022).

The United Nations Conference on Trade and Development (UNCTAD) provides information about the connectivity of shipping ports around the world. They use two different indicators to describe a port's position in the maritime network. The first metric is called the node degree, and it refers to the number of other docks with which the port has a direct link. The second metric is called node betweenness, and it describes the importance of a seaport in terms of the connectivity of other ports which are linked through it as a transshipment point (Hoffman, 2020).

The graph that follows presents a ranking of the top 20 ports according to their "betweenness."



* The port betweenness counts the amount of the shortest routes possible between two different ports (the minimum number of transshipments) that go through it.

Figure 4. The world's top 20 container ports ranked by betweenness in 2020.
Source: (UNCTAD, 2020).

We can see from this graph that three ports in North America have a high transshipment ratio. At first, we were planning to include the Port of Savannah in our investigation; however, since this port has a high transshipment rate, we have decided to substitute it with another port in order to maintain homogeneity in terms of a low transshipment rate. Since the ports of Mexico and Canada do not serve as major transshipment centers, we can include them in the research.

All of the seaports selected in the study reported at least 500 thousand TEUs in 2021, making this an additional element to consider when deciding ports. This is to reduce the variance between port throughputs. Since the United States has more alternatives for seaports with larger handled volumes, we have chosen seven ports from the United States, four from Canada, and four from Mexico, for a total of fifteen seaports.

According to Demirel (2009) to determine the number of samples needed for the study, it is recommended to be at least two times the total of outputs and inputs. But according to Cooper, Seiford and Tone (2006) there is a more accurate approach for calculating the minimum number of DMUs (Demirel, 2009, as cited in Cooper, Seiford and Tone, 2006):

$$N \geq MAX\ [m * s, 3(m + s)] \tag{7}$$

where N is the minimum number of DMUs needed, *m* is the quantity of inputs and *s* is the quantity of outputs.

In our study we are considering a total of 4 inputs and 1 output. Therefore:

$$N \geq MAX\ [4 * 1, 3(4 + 1)]$$
$$N \geq MAX\ [5, 15]$$

Since we are considering a total of 15 seaports, we can conclude that this condition has been satisfied.

3.4.2 Input and Output Parameters

For the purpose of our study, we will consider a total of 4 inputs, which are: quay length in meters, terminal area in hectares, number of quay cranes and the water depth in meters. Because they are the most important aspects of a terminal's overall operation, the first three are typically referred to in most of the studies that focus on determining port efficiencies, which is the reason they were selected for this research. The water depth at a seaport is of great significance since it determines the extent to which the port can accommodate various types of vessels, according to the dimensions of those ships. They are able to manage larger vessels up to a certain point, and that point increases with the depth of the sea. As a result, taking this factor into consideration is an important part of the evaluation.

Since, in some cases, we are considering more than one container terminal for each seaport, for the inputs of quay length, terminal area, and number of cranes, we will take the total amount of them and reflect it to be the value for that particular seaport. Regarding the water depth, we are going to use the average of the container terminals' observations and use that figure as the seaport's final value.

We will focus exclusively on a single output for our study, which is the throughput measured in TEUs. Most of the studies include this output when measuring the container terminal efficiencies. It is reasonable given that it represents the total amount of cargo that a port processes in a certain amount of time. The measures that are being presented in this paper are on a yearly basis. Since we want to consider the throughput that took place in years after pandemic, which are 2020 and 2021, we will take an average of these two periods to reflect the annual throughput of each port.

The ultimate figures for each seaport, including their inputs and outputs, are detailed in the following table during the time following the pandemic, which covers the years 2020 and 2021.

Country	***Seaport***	***Quay Length (m)***	***Terminal Area (ha)***	***Number of quay cranes***	***Water Depth (m)***	***Annual Throughput (thousands TEUs)***
Canada	Port of Vancouver	3,941	208	28	15.6	3,574
	Port of Montreal	2,770	98	17	12.6	1,668
	Port of Prince Rupert	800	32	8	17.0	1,098
	Port of Halifax	1,500	59	9	16.4	551
United States	Port of Los Angeles	9,915	688	79	15.5	9,945
	Port of Long Beach	8,194	492	69	14.9	8,749
	Port of New York and New Jersey	8,604	626	74	14.8	8,285
	Port of Savannah	2,955	544	30	12.8	5,148

	Northwest Seaport Alliance (NWSA)	6,330	427	50	15.4	3,528
	Port of Virginia	4,722	513	34	15.2	3,168
	Port of Oakland	6,285	303	36	14.4	2,455
	South Carolina Ports	1,920	243	20	13.7	2,530
Mexico	Port of Manzanillo	1,350	32	16	16.0	3,140
	Port of Lazaro Cardenas	1,500	49	7	16.5	1,377
	Port of Altamira	600	16	5	12.1	820
	Port of Veracruz	507	41	11	12.8	1,083

Table 3. Input and Output figures for each seaport.
Source: Own elaboration. (Based on figures collected from official seaports' websites).

Annexes 2 and 3 provide a complete overview of the input and output figures for each specific container terminal.

As a reference, the following table provides an overview of some input and output variable statistics.

Measure	***Quay Length (meters)***	***Terminal Area (hectares)***	***Number of quay cranes***	***Water Depth (meters)***	***Annual Throughput (thousands TEUs)***
Mean	3,929.18	255.19	30.87	14.86	3,464.41
Standard Deviation	3,209.67	237.54	25.65	1.48	3,042.64
Minimum	507.42	16.4	5	12.1	551
Maximum	9,915	688.4	79	17	9,945
Sum	58,938	3,828	463	223	51,966
Count	15	15	15	15	15

Table 4. Statistics overview of input and outputs values.
Source: Own elaboration

Since later on in the research we will be comparing the levels of efficiency that existed before and after the pandemic, we have also gathered the throughput output in TEUs for the time period before the pandemic, which includes the years 2017 and 2018. The following table provides an overview of the average throughput in TEUs for both the pre-pandemic and post-pandemic periods, which cover the years 2017/2018 and 2020/2021 respectively (in thousands TEUs).

Port	Period 2017 - 2018	Period 2020 - 2021
Port of Vancouver	3,324	3,574
Port of Montreal	1,608	1,668
Port of Prince Rupert	1,036	1,098
Port of Halifax	553	551
Port of Los Angeles	9,401	9,945
Port of Long Beach	7,818	8,749
Port of New York and New Jersey	6,945	8,285
Northwest Seaport Alliance (NWSA)	3,750	3,528
Port of Virginia	2,848	3,168
Port of Oakland	2,483	2,455
South Carolina Ports	2,247	2,530
Port of Manzanillo	2,954	3,140
Port of Lazaro Cardenas	1,232	1,377
Port of Altamira	812	820
Port of Veracruz	1,147	1,083

Table 5. Annual throughputs in TEUs for pre and post pandemic periods.
Source: Own elaboration. (Based on figures collected from official seaports' websites).

Since we utilize the same inputs and the same output for all DMUs and we are only evaluating data from container terminals, we can draw the conclusion that the homogeneity requirement from DEA model has been satisfied. Since the terminals constantly generate positive cargo throughput, the DEA requirement of positive values can likewise be considered satisfied.

The output-oriented results imply that, in the event that a DMU does not achieve an efficiency rate of 100%, the focus will be placed on modifying the outputs in order to achieve that efficiency, and the system will provide a suggestion on the quantity of output that is required to obtain the maximum efficiency rate.

In this study, we will be focusing on results that are output oriented since it is more feasible to achieve certain amount of throughput (TEUs), and it is quite challenging to make changes on the inputs that are currently being utilized. Additionally, we will be working on the CCR and BCC models in order to take into account both constant and variable returns to scale measures. We will make use of the RStudio application to get the DEA model to operate. It provides a package that is called "deaR", and it will be necessary to achieve the results that are required.

3.5 Conclusions of the Chapter

In this chapter, we were given the opportunity to study how the DEA methodology was initially introduced. According to what we've learnt, there are two distinct models: the CCR model, which takes into account constant returns to scale, and the BCC model, which reflects variable returns to scale. In addition to this, we discussed some of the advantages and drawbacks of the model, as well as how it compared to the Stochastic Frontier Analysis. For our data collection, we reviewed the criteria we used to select the seaports for our study, which takes into consideration only container terminals, seaports that don't have a high transshipment rate, and only seaports that processed an annual volume of more than 500 thousand TEUs. We are considering a total of 4 inputs, that include quay length in meters, terminal area in hectares, number of quay cranes and the water depth in meters. For our output we will consider the annual throughput in TEUs for the periods of 2020 and 2021.

Chapter 4. Results and Analysis

4.1 Introduction of the Chapter

The results of the research will be discussed in this section of the report. First, a summary of the efficiency rates, the input slacks, the targets, and the reference (peers) is presented. Following that, an interpretation of these results is provided. And finally, a comparison of the efficiency rates is shown, taking into consideration the output volumes in TEUs for both the pre-pandemic and post-pandemic time periods.

4.2 Results Overview

The efficiency scores were obtained using the RStudio package "deaR". A sample of the RStudio code can be found in Annex 4. Four inputs and one output were chosen for the research with output-oriented approach. We are evaluating both the CCR and BCC models, which assume constant and variable returns to scale, respectively. Constant returns to scale (CRS) accounts for overall efficiency, variable returns to scale (VRS) is pure technical efficiency and SE will be the scale efficiency. A total of 15 seaports were considered in the study and the efficiency scores for each of them can be found in the following table.

Country	Port	CCR	BCC	SE
Canada	Port of Vancouver	0.811	0.819	0.990
	Port of Montreal	0.565	0.764	0.740
	Port of Prince Rupert	0.699	0.760	0.919
	Port of Halifax	0.312	0.312	1.000
USA	Port of Los Angeles	1.000	1.000	1.000
	Port of Long Beach	1.000	1.000	1.000
	Port of New York and New Jersey	0.924	0.989	0.934
	Northwest Seaport Alliance (NWSA)	0.520	0.523	0.995
	Port of Virginia	0.630	0.644	0.979
	Port of Oakland	0.474	0.499	0.951
	South Carolina Ports	0.760	0.941	0.807
Mexico	Port of Manzanillo	1.000	1.000	1.000
	Port of Lázaro Cárdenas	1.000	1.000	1.000
	Port of Altamira	0.835	1.000	0.835
	Port of Veracruz	0.917	1.000	0.917

Table 6. Summary of score efficiencies.
Source: Own elaboration.

As can be seen, the BCC efficiency scores are higher, which is to be expected given that BCC takes into account only technical efficiency with variable returns to scale and it is more flexible. The scale efficiency was determined by taking the constant returns to scale measures and dividing them by the variable returns to scale. For CCR, only four seaports managed to get a score of 100% of efficiency, while for BCC, six seaports were able in achieving the highest score.

If we look at the summary of statistics, we can see that the BCC score for all of the seaports has a mean of 0.76, while the BCC score has a mean of 0.81, which is evidence that BCC gives higher efficiency scores than the CCR model does.

Measure	CCR	BCC
Mean	0.7632	0.8166
Standard Error	0.0573	0.0588
Minimum	0.3116	0.3116
Maximum	1.0000	1.0000
Sum	11.4475	12.2497
Count	15	15

Table 7. Summary of CCR and BCC model score statistics.
Source: Own elaboration.

The input *slack* can be viewed as the surplus resources that companies can exploit to achieve the highest possible efficiency score. Input slack implies that input can be decreased without impacting output quantity. Therefore, if a port is 100% efficient, there will be no slacks. The following table depicts the input slacks observed by the analysis.

Port	Slack Input Quay Length (m)	Slack Input Terminal area (ha)	Slack Input Number of Quay Cranes	Slack Input Water Depth (m)
Port of Vancouver	944	48	0	0
Port of Montreal	1110	27	0	0
Port of Prince Rupert	0	11	0	8
Port of Halifax	32	14	0	0

Port of Los Angeles	0	0	0	0
Port of Long Beach	0	0	0	0
Port of New York and New Jersey	0	78	3	0
Northwest Seaport Alliance (NWSA)	340	38	0	0
Port of Virginia	891	288	0	0
Port of Oakland	2142	51	0	0
South Carolina Ports	0	165	0	0
Port of Manzanillo	0	0	0	0
Port of Lazaro Cardenas	0	0	0	0
Port of Altamira	12	0	0	5
Port of Veracruz	0	29	5	7

Table 8. Input slack values CCR model.
Source: Own elaboration.

This indicates that each port has the potential to lower their inputs for the quantities that are being provided in order to maintain the same level of outputs. The ports that have 100% efficiency scores have zero slacks since they have already achieved the highest level of efficiency and there is no need for them to cut any inputs as a result of this performance.

The *targets* that were obtained by the model reflect the ideal value that the seaports should strive to achieve in order to reach high levels of efficiency. Because we are concentrating our research on output-oriented model, the table that follows presents the target output values for each port.

Port	Target Annual Throughput (thousand TEUs)
Port of Vancouver	4,409
Port of Montreal	2,951
Port of Prince Rupert	1,570
Port of Halifax	1,768
Port of Los Angeles	9,945
Port of Long Beach	8,749
Port of New York and New Jersey	8,965
Northwest Seaport Alliance (NWSA)	6,782
Port of Virginia	5,026
Port of Oakland	5,173
South Carolina Ports	3,330
Port of Manzanillo	3,140

Port of Lazaro Cardenas	1,377
Port of Altamira	982
Port of Veracruz	1,180

Table 9. Target values CCR model.
Source: Own elaboration.

The ports that resulted in an efficiency level of 100% exhibit the same amount of throughput as the initial values. This is because, since they are receiving the highest efficiency, the starting value that they obtained as output is sufficient for them to be considered an efficient port. The ports that obtained a lower efficiency, on the other hand, show a target value of output that is more than the initial value; this indicates that in order for them to be considered efficient, they would need to attain this new amount of output.

An inefficient terminal needs to determine the best practices for its resources by consulting its *peers*, who serve as references. This will help the terminal become more efficient. Within the context of data envelopment analysis, these comparable entities are known as "references," and the values assigned to their respective weights are referred to as "lambda" values. The investigation produces a virtual terminal including at least one DMU that is effective, as well as the peer weights that match to those DMUs. (Basavaraj, 2021).

The table that follows provides an overview of these references for each port. Given that it has already reached its maximum level of efficiency, the ports that have achieved efficiency of 100 percent serves as its own peer in this scenario showing 1 (100%) to its own port.

Port	Port of Los Angeles	Port of Long Beach	Port of Manzanillo	Port of Lazaro Cardenas
Port of Vancouver	19.5%	0	78.6%	0
Port of Montreal	6.9%	0	72.0%	0
Port of Prince Rupert	0	0	44.0%	13.8%
Port of Halifax	0	0	22.2%	77.9%
Port of Los Angeles	1	0	0	0
Port of Long Beach	0	1	0	0
Port of New York and New Jersey	34.4%	63.4%	0	0
Northwest Seaport Alliance (NWSA)	54.5%	0	43.3%	0

Port of Virginia	29.6%	0	66.3%	0
Port of Oakland	34.0%	0	57.0%	0
South Carolina Ports	0	11.0%	75.3%	0
Port of Manzanillo	0	0	1	0
Port of Lazaro Cardenas	0	0	0	1
Port of Altamira	0	0	23.3%	18.3%
Port of Veracruz	0	0	37.6%	0

Table 10. Lambda values (weighted peers) CCR model.
Source: Own elaboration.

It is not unusual that the four seaports included in table as references are used as examples for the others, since they achieved a larger degree of efficiency when compared to the other seaports. According to Basavaraj (2021) the ports that did not get a high level of efficiency need to look at the terminal that was suggested by the model. This terminal is the one that is composed by the total of the percentages; for example, the Port of Vancouver would need to take as reference both the Port of Los Angeles, which has a percentage level of 20%, and the Port of Manzanillo, which has a percentage level of 79%. However, given that they are unable to take into account a single reference that is produced by two separate ports, they are only able to select the port that has a greater percentage and use it as a benchmark, which in this instance is the Port of Manzanillo.

4.3 Results Analysis

In this section, we will conduct an analysis of the results that were reported in the previous section (section 4.2). We will analyze the port's efficiency scores, slacks, and targets.

4.3.1 Efficiency Levels

Based on the analysis of the efficiency levels, the overall results of the CCR model reveal that just 4 of the 15 seaports that were analyzed can be called efficient, whereas the results of the BCC model show that 6 of the ports may be declared efficient. The following are the seaports that performed well in both models: Port of Los Angeles and Port of Long Beach in United States, and from Mexico Port of Manzanillo and Port of Lazaro Cárdenas. None of the ports in Canada were able to achieve full efficiency score.

The following table provides a ranking of the efficiencies that were found with CCR model.

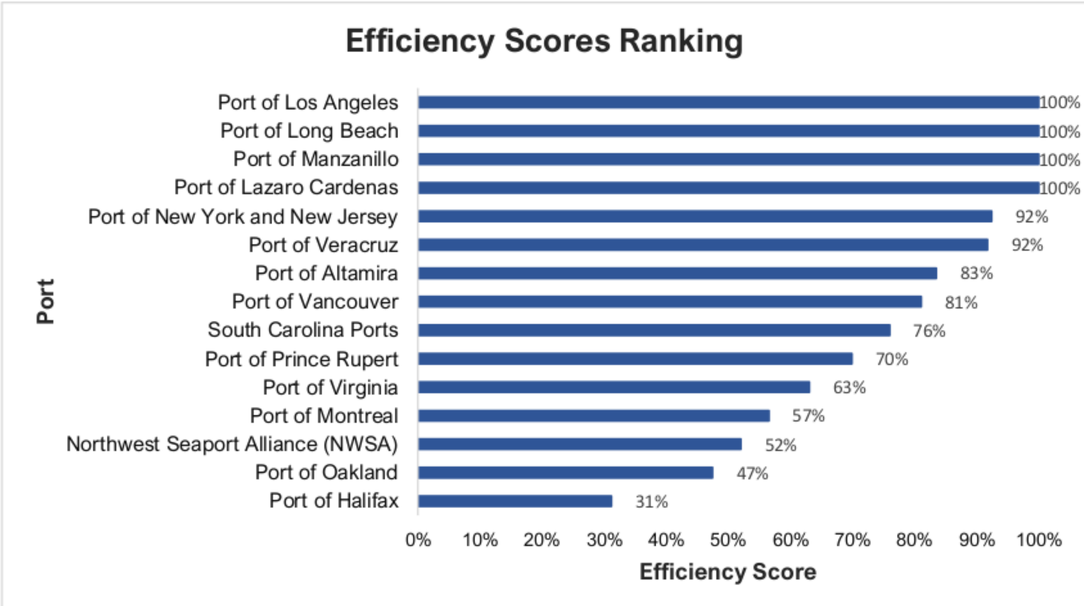


Figure 5. Ranking of efficiency scores.
Source: Own elaboration.

We can observe, by the use of the CCR model, that the four seaports that have achieved the highest level of efficiency are the Port of Los Angeles, Long Beach, Manzanillo and Lazaro Cardenas.

The Port of Los Angeles and the Port of Long Beach have been particularly hard struck as a result of the increase in the overall volume of maritime transport after pandemic. There have been some studies done on efficiency, but the approach that they are taking is related to the amount of time that a ship spends waiting for service. In this particular scenario, these two ports have got low rates of efficiency (Gordon, 2022). However, if we take into consideration not the amount of time that a ship is waiting but rather the infrastructure that they have available, we can see that these ports are rating a good efficiency level. In addition, we need to highlight the fact that these ports are now handling record levels of throughput; for instance, the Port of Los Angeles set a new historical record of 10.7 million TEUs that were processed in 2021 (Port of Los Angeles, 2022).

Therefore, according to the findings of this research, these two ports are operating and using their resources effectively even though they are having trouble keeping up with the increase in volume.

Regarding the situation of Mexican ports, the Port of Manzanillo and the Port of Lazaro Cardenas both obtained the maximum level of efficiency. A rise in the number of TEUs that were handled at these two ports contributed to the overall trend. In the instance of the Port of Manzanillo, it was by far the busiest port in Mexico, achieving a total yearly volume of 3.37 million TEUs. This was followed by the Port of Lazaro Cardenas, which had a volume of 1.69 million TEUs, and both of these ports are located on the West side of Mexico. In 2021, the amount of traffic that passed through ports on the Pacific Coast increased at a quicker rate of 23.7% when compared to the amount that passed through ports on the Gulf Coast in 2021, which increased by 11.5% year on year (Holt & Lademan, 2022). As a result, we are able to draw the premise that these two Mexican ports have been making effective use of their resources in response to the increase in volume.

The Port of New York and New Jersey, as well as the Port of Veracruz, come next in the ranking with 92 percent. These two did not succeed in reaching the highest possible level of efficiency, but the end result is still satisfactory. In comparison to the years before, these two ports have seen a significant increase in the volume of their operations. However, despite the fact that they could make better use of their resources, they are demonstrating a high degree of efficiency regardless.

The ports that were considered to have a degree of efficiency that fell in the middle of the ranking between 50% and 90% are Port of Altamira, Vancouver, South Carolina, Prince Rupert, Virginia, Montreal, and the Northwest Seaport Alliance (NWSA). These ports demonstrate that they can make more efficient use of their current resources. Next in this section we will go through some of the activities or goals that they can set in order to raise the degree of efficiency.

The two ports with the lowest efficiency rankings are the Port of Oakland (47%) and the Port of Halifax (31%). Currently, these two ports are utilizing their resources in an inefficient manner, thus an evaluation of their current practices is necessary.

If we examine the statistics by country, we discover that Canada has the least efficient ports on average, whereas the United States and Mexico have greater average levels of efficiency. The following table provides a summary of the efficiency percentages by country, while the graph illustrates the average efficiency by country.

Measure	Canada	USA	Mexico
Mean	60%	76%	94%
Minimum	31%	47%	83%
Maximum	81%	100%	100%
Sum	239%	531%	375%
Count	4	7	4

Table 11. Summary statistics of efficiency scores by country.
Source: Own elaboration.

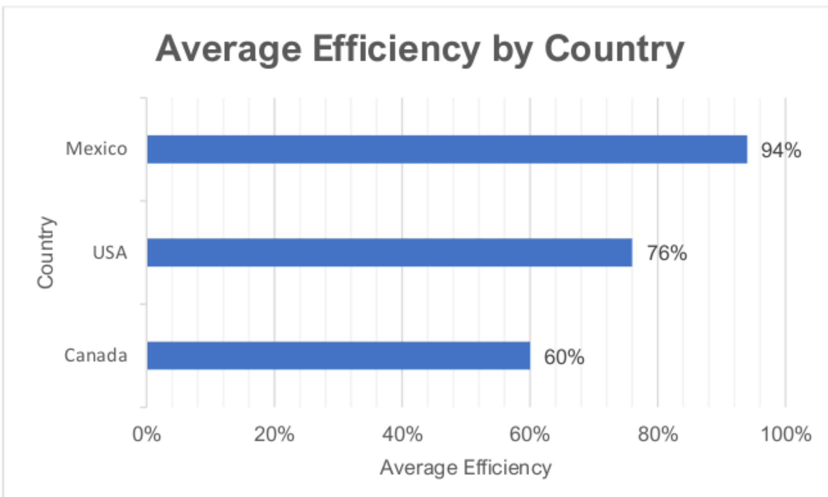


Figure 6. Average efficiency distributed by country.
Source: Own elaboration.

Canada is the only country where none of its seaports have achieved 100 percent efficiency. The Port of Vancouver ranks highest at 81%, yet this port has also struggled to handle the spike in volume, indicating that they are not exploiting their resources in an efficient way. Given the severe supply disruptions that have come from the economic recovery after the COVID recession, port efficiency has assumed a new urgency, and since Port of Vancouver is the primary entry point for consumer products entering Canada from Asia's manufacturing powerhouses, immediate action is required (Friedman, 2022).

The results of analyzing the average efficiency by coast are as follows. The following table provides an overview of statistics, while the graph below illustrates the distribution of average efficiencies.

Measure	West	East
Mean	81%	71%
Minimum	47%	31%
Maximum	100%	92%
Sum	650%	494%
Count	8	7

Table 12. Summary statistics of efficiency scores by coast.
Source: Own elaboration.

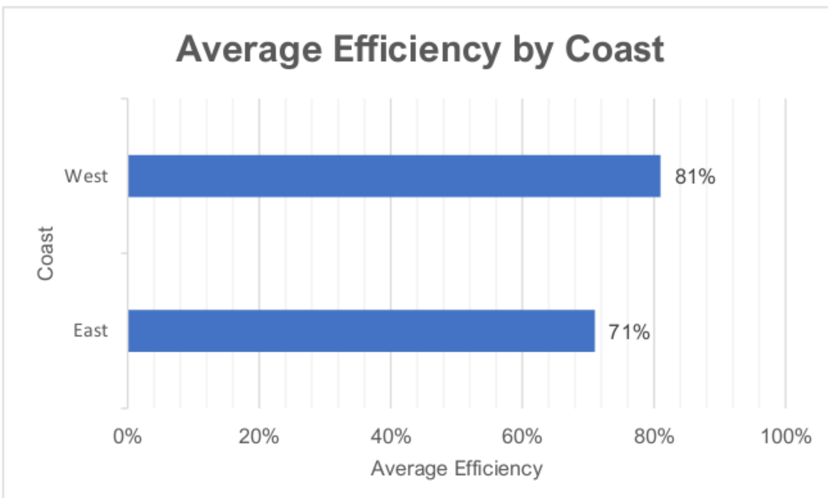


Figure 7. Average efficiency distributed by coast.
Source: Own elaboration.

This data indicates that the west coast ports are handling cargo more efficiently than their east coast counterparts. The four most efficient seaports are located on the west coast of America, facing the Pacific Ocean. Some East Coast ports achieved a reasonable level of efficiency, but none of them reached 100 percent.

4.3.2 Slacks

The slack can be considered as the excess resources that businesses can utilize to attain the maximum potential efficiency score, as previously discussed. If a port is 100 percent efficient, there will be no slacks.

The quay length and the terminal area are the inputs for which we can observe a higher level of slacks. When it comes to quay length, a number of ports that have a lower rate of efficiency have a significant amount of spare capacity for this input. The largest amount of slack (Table 8) may be seen at the Port of Oakland, which is 2,142 meters. This indicates that this port could cut this input by this quantity, and if it did so, while maintaining the same amount of output, it would achieve an efficiency level of 100%. Other ports with a medium level of efficiency, such as Montreal, Vancouver, and Virginia, also display a significant amount of quay length slack.

The ports of Virginia, South Carolina and New York and New Jersey represent the highest degree of slack when it comes to the terminal area. This indicates that they are not making the most effective use of this resource. When it comes to quay cranes, there are only two seaports that are exhibiting slack values. These are the port of New York and New Jersey, as well as the Port of Veracruz. On this input, none of the other seaports are reporting any slack. And finally, with regards to the input of water depth, there are just three seaports displaying slack values. These ports are Veracruz, Altamira, and the Port of Prince Rupert.

These slack values in inputs would serve only as a reference for the study we are conducting, showing how some resources are not being used as efficiently as they could be. It would be quite difficult to actually lower these inputs, thus this is only an approach to demonstrate how these resources could be utilized in a more efficient manner. Considering the possibility of lowering them, would be very complex for the port entities, since the inputs we are considering are costly infrastructure and equipment that is difficult to change.

4.3.3 Targets

The targets that were generated by the model indicate the ideal value that the seaports should seek to achieve in order to attain high levels of efficiency, as stated previously.

The following table presents the target throughputs that were calculated by the model; the values in the first column "Target Throughput TEUs" represent the quantity of TEUs that each port need to pursue in order to achieve a high level of efficiency; the following column "Actual Throughput TEUs" presents the actual throughput that each port achieved, and the last column "Difference in Throughput TEUs" provides the difference between the two, that is the additional quantity of TEUs that each port should have to produce in order to achieve a high level of efficiency. The ports that achieved a level of efficiency of 100% exhibit a value of zero for difference since the quantity suggested by the model and the quantity that they actually obtained are the same.

Port	Target Throughput TEUs	Actual Throughput TEUs	Difference in Throughput TEUs
Port of Vancouver	4,409	3,574	835
Port of Montreal	2,951	1,668	1,283
Port of Prince Rupert	1,570	1,098	473
Port of Halifax	1,768	551	1,217
Port of Los Angeles	9,945	9,945	0
Port of Long Beach	8,749	8,749	0
Port of New York and New Jersey	8,965	8,285	680
Northwest Seaport Alliance (NWSA)	6,782	3,528	3,254
Port of Virginia	5,026	3,168	1,859
Port of Oakland	5,173	2,455	2,719
South Carolina Ports	3,330	2,530	800
Port of Manzanillo	3,140	3,140	0
Port of Lazaro Cardenas	1,377	1,377	0
Port of Altamira	982	820	162
Port of Veracruz	1,180	1,083	98

Table 13. Comparison of target and actual output throughput.
(* in thousands TEUs).
Source: Own elaboration.

The following graph illustrates, for each port, the surplus that would need to be produced (the difference column on the table above) in order to achieve the highest possible level of efficiency. In this scenario, each port should be analyzed individually given the fact that the annual volumes produced by each port are different from one another.

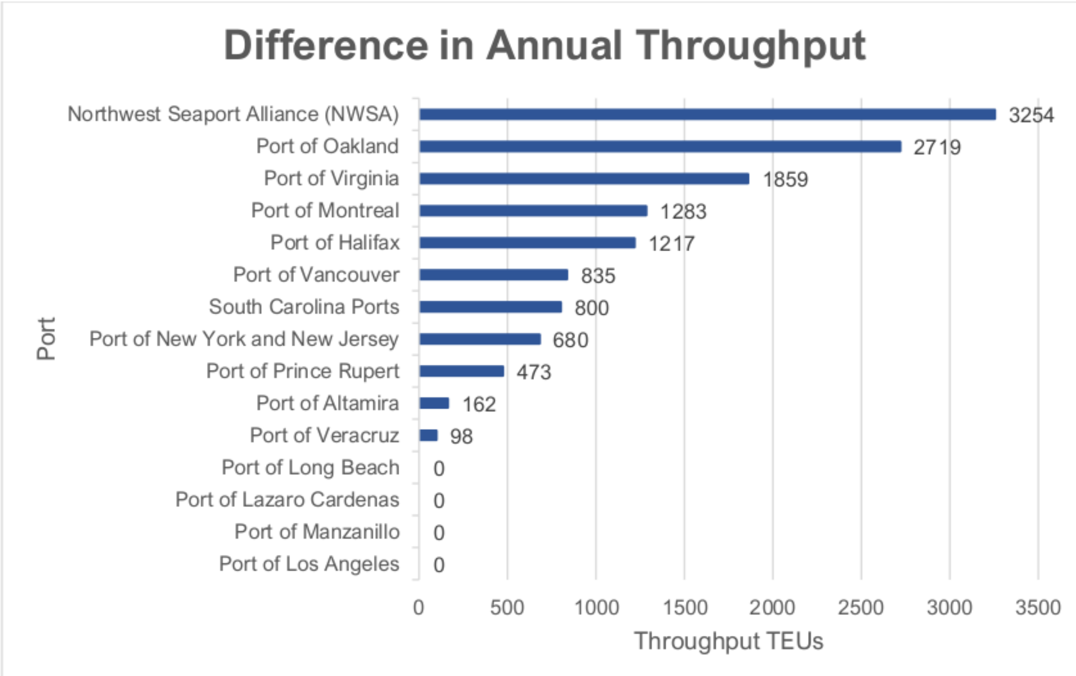


Figure 8. Extra throughput in TEUs to achieve efficiency.
Source: Own elaboration.

Based on our analysis of this graph, we can infer that in order for the Northwest Seaport Alliance (NWSA) to attain a high level of efficiency, they will need to establish a target of creating an additional number of TEUs equal to 3,254. The same can be said for the Port of Oakland, which would need to produce an extra amount of 2,819 TEUs, and for Virginia with 1,859 TEUs. The seaports that have already achieved the highest possible level of efficiency have a surplus of zero since they are already operating at an efficient level.

4.3.4 Comparison of pre and after pandemic efficiency scores

The purpose of this study is to evaluate the efficiency of the selected seaports using post-pandemic information, so that appropriate action may be taken based on the most current data. Just as a basis of reference, we will compare the efficiency scores with pre-pandemic throughputs, which include TEUs processed between 2017 and 2018, and post-pandemic throughputs, which are between 2020 and 2021, when an increase in demand volume was observed. The following graph illustrates the efficiency scores for each port, comparing the levels before and after the pandemic.

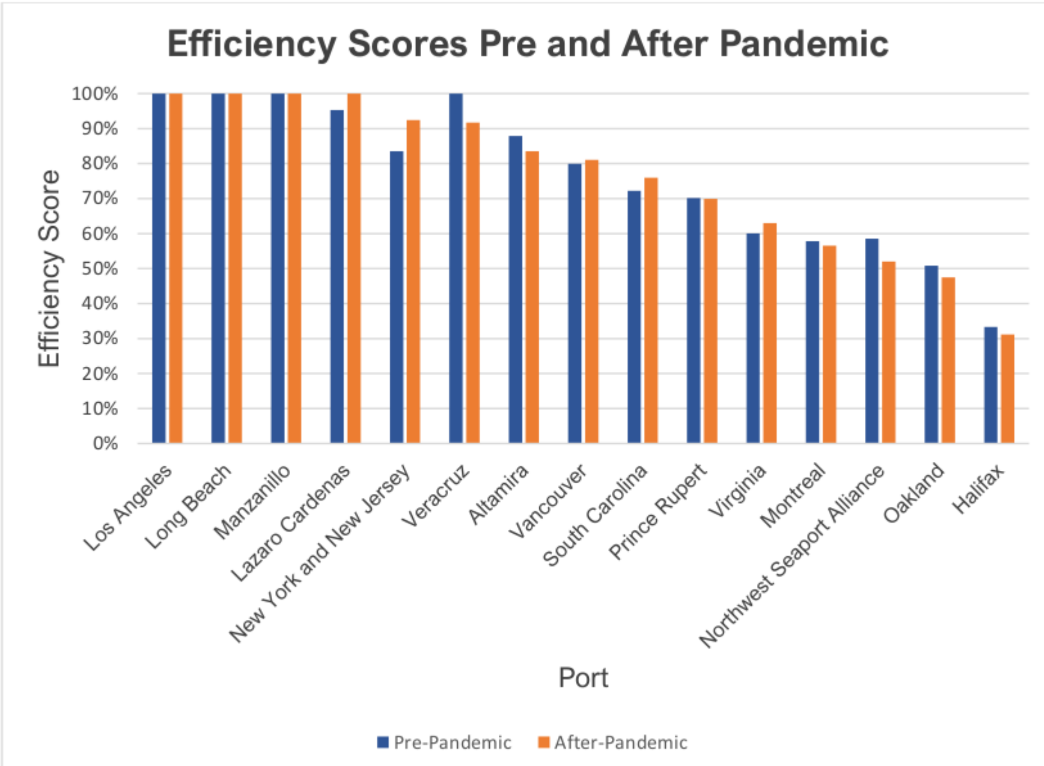


Figure 9. Comparison of pre and after pandemic efficiency scores.
Source: Own elaboration.

According to the data, we are able to see that some of the ports, including Los Angeles, Long Beach, and Manzanillo, which had the highest score of efficiency, were already functioning with a high degree of efficiency before the pandemic. There are only five ports out of the fifteen that improved their level of efficiency after the outbreak, one of which is Lazaro Cardenas, which reached a level of efficiency of one hundred percent after the pandemic. The efficiency level of the remaining seaports, which total six, after the pandemic was slightly diminished. When a rise in volume was detected, the available resources in these ports may have been mismanaged, which led to this issue. In general, we are able to determine that there is not a significant change that took place between the two periods of time.

4.4 Conclusions of the Chapter

In this chapter, the results of the DEA methodology were presented. First, the efficiency scores for each seaport, considering CCR model, which accounts for constant returns to scale, BCC model, which represents variable returns to scale and the scale efficiency. The Port of Los Angeles, Port of Long Beach, Port of Manzanillo, and Port of Lazaro Cardenas were the four seaports in achieving the highest efficiency level on both models.

Then, the input slacks were shown, which can be interpreted as the surplus resources that seaports could reduce, and, while maintaining the same output, they could reach the highest level of efficiency. In addition to this, we determined the target values, which represent the ideal output that the seaports would need to process in order to achieve a level of efficiency of 100%. in the case of the ports that have already achieved this degree of efficiency, the target values are equal to the output values. Additionally, the references or peers for each port were given. The peers are comparable seaports that each port can utilize as a reference in order to apply similar practices in to achieve higher levels of efficiency.

Finally, for reference purposes, we compared the efficiency scores we obtained using throughput data both before and after the pandemic. According to the findings, certain ports, such the Port of Los Angeles and the Port of Long Beach, were already functioning at a high level of efficiency well before the increase in the volume of trade that took place.

Chapter 5. Conclusions and Recommendations

5.1 Conclusions

The purpose of this thesis is to determine which ports in North America have the highest levels of efficiency in account of the increase in volume of trade that occurred after the COVID outbreak. This study could be helpful to port authorities, governments, or private enterprises affiliated with the considered seaports in order for them to make appropriate actions to boost efficiency in the event that they acquired a lower level of it and understand their current position.

In order to determine the degrees of efficiency, the technique known as data envelopment analysis (DEA) was utilized. RStudio was the platform used to run the model and the package used from this program is called “deaR”.

In total, 15 seaports across North America were taken into consideration for this analysis, specifically, 4 ports from Canada, 7 ports from the United States, and 4 ports from Mexico. To maintain the homogeneity needed for this method we are analyzing only container terminals, also only ports with a low transshipment rate and only seaports that reported more than 500 thousand TEUs as throughput in the prior year.

We are conducting research on both the CCR and BCC models, which take into account constant and variable returns to scale, respectively, utilizing 4 inputs, which are quay length in meters, terminal area in hectares, number of quay cranes and the water depth in meters, and 1 output, which is the total throughput of the container port in TEUs, and output-oriented results. To consider the period after pandemic, we are taking the TEU volumes of years 2020 and 2021, calculating an average of the two and using it as our output.

According to the results, four ports managed to reach an efficiency level of 100% on both models CCR and BCC, which are the Port of Los Angeles, Port of Long Beach, Port of Manzanillo, and Port of Lazaro Cardenas. Following the pandemic, these four ports saw an increase in volume and yet they continue to operate at a high level of efficiency. For instance, the Port of Los Angeles reached an historic record for the volume of TEUs it processed in 2021, when it hit 10.7 million.

There were ports that achieved a medium level of efficiency, such as the Port of New York and New Jersey, the Port of Altamira, or the Port of Vancouver, and there were also ports that achieved less than 50% efficiency, such as the Port of Halifax in Canada. These ports need to work in order to boost and improve the overall efficiency, and in order to have an idea of where they should focus more of their effort, the model offers a few tools for this purpose.

The input slacks that are calculated by the model are the resources that are not being used in an effective manner. A high degree of efficiency might be obtained by minimizing these slacks while maintaining the same output level. In this situation, the slack would simply be used as a reference so that organizations could identify which resources were not being used effectively. This is because actually decreasing the amount of slack would be difficult since adjusting the infrastructure or equipment may be very costly.

In addition to this, we are provided with the target values, which represent the optimal level of output that companies should work to achieve in order to obtain a high level of efficiency. For the ports that have already reached their maximum level of efficiency, this target value will remain the same as the actual throughput that those ports handled. And finally, the references or peers are the comparable entities that inefficient ports should look at in order to replicate the best techniques and achieve a higher efficiency score.

Lastly, we did a comparison between the efficiency rates that were obtained with throughputs both before and after the pandemic only as a point of reference. It is noticeable that the results are not very distinct from one another. The Port of Los Angeles, the Port of Long Beach, and the Port of Manzanillo were the three ports that were functioning with high efficiency even before the outbreak hit.

5.2 Limitations

Since we need to follow a requirement of homogeneity, we were restricted to selecting only container terminals that had comparable transshipment rates and a particular TEU yearly throughput. This could limit our study and exclude some ports that were of interest to see, such as the Port of Savannah, which is one of the busiest ports in the United States. However, due to the fact that it has a high transshipment rate, it was decided to exclude it from the study in order to keep homogeneity to the highest extent possible.

Since our research is focused on seaports, which have infrastructure and equipment that is difficult to alter, the input slacks obtained by the model are merely for reference purposes. However, the information provided is extremely valuable for determining which resources are not being utilized as efficiently as possible. It might be possible to begin taking certain activities in order to change these inputs but doing so would take a considerable amount of time and would be expensive.

5.3 Recommendations for further research

Additional research can be carried out in order to overcome some of the limitations that were discussed earlier. The study can be broadened to include ports with higher transshipment rates in order for us to examine the ports that were not addressed during this research. In addition, a variety of port capacities, with some of them handling less than 500,000 TEUs annually can be analyzed.

Because we are only concentrating on container terminals, future research might potentially look at other types of cargo, such as liquid or bulk freight. And finally, there are some other inputs and outputs that may be included in the analysis. Inputs such as labor, which can have an effect on the efficiency of seaports, and outputs, such as revenue.

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Appendices.

Annex 1. List of container terminals considered in analysis.

Port	Container Terminal
Port of Vancouver	Centerm - DP World
	Deltaport - Global Container Terminals
	DP World Fraser Surrey
	Vanterm - Global Container Terminals
Port of Montreal	Maisonneuve
	Viau
	Cast
	Racine
Port of Prince Rupert	Fairview Container Terminal
Port of Halifax	PSA Halifax Fairview Cove
	PSA Halifax Atlantic Hub
Port of Los Angeles	APM Terminals Pacific LLC
	Everport Container Terminal
	Fenix Marine Services
	Trapac Container Terminal
	Yusen Container Terminal
	China Shipping (Holding) NA
	Everglades Company Terminal
Port of Long Beach	Pier G - Container Terminal
	Pier E - Container Terminal
	Pier J - Pacific Container Terminal
	Pier A - SSA Terminals
	Pier C - SSA Terminals
	Pier T - Total Terminals International
The Port of New York and New Jersey	Port Newark Container Terminal
	Maher Terminals
	APM Terminals
	GCT New York Terminal
	GCT Bayonne Terminal
	Red Hook Container Terminal
Northwest Seaport Alliance (NWSA)	T-5 Seattle
	T-18 Seattle
	T-30 Seattle
	West Sitcum Tacoma
	Husky Tacoma
	East Sitcum Tacoma
	PCT Tacoma

	WUT Tacoma
Port of Virginia	Norfolk International Terminals (NIT)
	Virginia International Gateway (VIG)
	Portsmouth Marine Terminal (PMT)
	Richmond Marine Terminal (RMT)
Port of Oakland	Ports America Outer Harbor Terminal
	TraPac Terminal
	Ben E. Nutter Terminal (STS/Evergreen)
	Oakland International Container Terminal
	Matson Terminal
	Charles P. Howard Terminal
South Carolina Ports	Wando Welch Terminal
	North Charleston Terminal
Port of Manzanillo	SSA Mexico
Port of Lazaro Cardenas	APM Terminal
Port of Altamira	ATP - Altamira Terminal Portuaria
Port of Veracruz	Terminal I Icave

Annex 2. List of input figures for each container terminal.

Container Terminal Name	Quay Length (meters)	Terminal Area (hectares)	Number of quay cranes	Water Depth (meters)
Centerm - DP World	647	29	7	15.5
Deltaport - Global Container Terminals	1,100	85	12	15.9
DP World Fraser Surrey	1,575	63	3	15.5
Vanterm - Global Container Terminals	619	31	6	15.5
Maisonneuve	630	20.2	4	12.6
Viau	630	22.2	4	12.6
Cast	740	30.7	4	12.6
Racine	770	24.6	5	12.6
Fairview Container Terminal	800	32	8	17.0
PSA Halifax Fairview Cove	700	28.3	4	16.8
PSA Halifax Atlantic Hub	800	31	5	16
APM Terminals Pacific LLC	2,225	196	19	16.8
Everport Container Terminal	1,768	82	8	14.3
Fenix Marine Services	1,219	118	16	15.2
Trapac Container Terminal	1,411	89	10	16.2
Yusen Container Terminal	1,768	75	11	16.2

China Shipping (Holding) NA	762	53.4	10	16.2
Everglades Company Terminal	762	75	5	13.7
Pier G - Container Terminal	1,945	99.6	15	12.8
Pier E - Container Terminal	1,280.2	68.8	10	16.8
Pier J - Pacific Container Terminal	1,799	103.6	17	15.2
Pier A - SSA Terminals	1,097	64	10	15.2
Pier C - SSA Terminals	549	28..3	3	12.8
Pier T - Total Terminals International	1,524	155.8	14	16.8
Port Newark Container Terminal	1,165	110	13	15.2
Maher Terminals	3,087	182	24	15.2
APM Terminals	1,829	142	15	15.2
GCT New York Terminal	701	85	6	16
GCT Bayonne Terminal	821.5	68.4	8	14.4
Red Hook Container Terminal	1,000	38.6	8	12.8
T-5 Seattle	884	75	4	15.2
T-18 Seattle	1,353	79	10	15.2
T-30 Seattle	818	33	6	15.2
West Sitcum Tacoma	671	43.7	5	15.5
Husky Tacoma	902	48	8	15.5
East Sitcum Tacoma	274	15	4	15.5
PCT Tacoma	636	76	7	15.5
WUT Tacoma	792	57	6	15.5
Norfolk International Terminals (NIT)	2,021	230	14	15.2
Virginia International Gateway (VIG)	1,143	118	12	15.2
Portsmouth Marine Terminal (PMT)	1,079	116	6	15.2
Richmond Marine Terminal (RMT)	478.5	49	2	15.2
Ports America Outer Harbor Terminal	1714	85.1	10	15.2
TraPac Terminal	662	26.6	4	15.2
Ben E. Nutter Terminal (STS/Evergreen)	657.4	29.9	4	15.2
Oakland International Container Terminal	1,822.5	109.2	10	15.2
Matson Terminal	836	32.1	4	12.8
Charles P. Howard Terminal	593	20.4	4	12.8
Wando Welch Terminal	1,158.24	162	15	13.7
North Charleston Terminal	762	81.3	5	13.7
SSA Mexico	1,350	32	16	16
APM Terminal	1,500	49	7	16.5
ATP - Altamira Terminal Portuaria	600	16.4	5	12.1
Terminal I Icave	507.42	41	11	12.8

Annex 3. List of output figures for each year.
(* in thousands TEUs)

Country	Port	TEUs 2017	TEUs 2018	TEUs 2020	TEUs 2021
Canada	Port of Vancouver	3,252	3,396	3,468	3,679
Canada	Port of Montreal	1,537	1,679	1,607	1,728
Canada	Port of Prince Rupert	1,036	1,036	1,141	1,054
Canada	Port of Halifax	559	547	507	595
USA	Port of Los Angeles	9,343	9,458	9,213	10,677
USA	Port of Long Beach	7,544	8,091	8,113	9,384
USA	The Port of New York and New Jersey	6,710	7,179	7,585	8,985
USA	Northwest Seaport Alliance (NWSA)	3,702	3,797	3,320	3,736
USA	Port of Virginia	2,841	2,855	2,813	3,522
USA	Port of Oakland	2,420	2,546	2,461	2,448
USA	South Carolina Ports	2,177	2,316	2,309	2,751
Mexico	Port of Manzanillo	2,830	3,078	2,909	3,370
Mexico	Port of Lazaro Cardenas	1,149	1,314	1,063	1,690
Mexico	Port of Altamira	803	820	877.3	762
Mexico	Port of Veracruz	1,117	1,176	1,005	1,160

Annex 4. Sample RStudio code.

```
library(dplyr)
library(deaR)
# Importing data with deaR package.
DataR <- deaR::read_data(datadea=Data,
                         ni=4,
                         no=1,
                         dmus=1,
                         inputs=2:5,
                         outputs=6:6)
# Modeling basic DEA with output orientation oo - BCC.
result_oo_BCC <- deaR::model_basic(DataR,
                                   dmu_eval = 1:15,
                                   dmu_ref = 1:15,
                                   orientation="oo",
                                   rts="vrs")
#Efficiency percentages and scores.
Score_oo_BCC <- deaR::efficiencies(result_oo_BCC)
data.frame(Score_oo_BCC)
```