

Evaluation of the Operational Efficiency of Brazilian Ports in Corn Handling between 2019 and 2023

*Avaliação da Eficiência Operacional dos Portos Brasileiros na
Movimentação de Milho entre os Anos de 2019 e 2023*
*Evaluación de la eficiencia operativa de los puertos brasileños en la
manipulación del maíz entre los años 2019 y 2023*

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Abstract:

This project aims to showcase the performance of the main Brazilian ports by calculating the average operational berth productivity, combining the use of technological tools such as Python and Power BI to build a visualization of the national port scenario in corn handling. Using the Data Envelopment Analysis (DEA) model, a ranking was developed to classify the ports based on their installed infrastructure and the total cargo handled from 2019 to 2023. As a result, the integration of these information technology tools within the logistics context enables the assessment of the port sector in Brazil.

Keywords: Efficiency; Logistics; Ports; Corn; Productivity.

Resumo:

Este projeto tem como objetivo mostrar o desempenho dos principais portos brasileiros que movimentam milho. O desenvolvimento foi guiado pelo cálculo da prancha média operacional, combinando o uso de ferramentas tecnológicas como Python e Power BI para construir uma visualização do cenário portuário nacional na movimentação de milho. Utilizando o modelo analítico DEA (Análise de Envoltória de Dados), foi elaborado um ranking que classifica os portos com base na infraestrutura instalada e no total de cargas movimentadas nos anos de 2019 à 2023. Como resultado, a integração dessas ferramentas de tecnologia da informação no contexto da logística permite avaliar o setor portuário no Brasil.

Palavras-chave: Eficiência; Logística; Portos; Milho; Produtividade.

Resumen:

Este proyecto tiene como objetivo mostrar el rendimiento de los principales puertos brasileños que gestionan el maíz. El desarrollo se guió por el cálculo del consejo operativo medio, combinando el uso de herramientas tecnológicas como Python y Power BI para construir una visualización del escenario del puerto nacional en el movimiento del maíz. Utilizando el modelo analítico DEA (Data Envelopment Analysis), se preparó una clasificación que clasifica los puertos según la

infraestrutura instalada y la carga total manejada en los años 2019 a 2023. Como resultado, la integración de estas herramientas de tecnología de la información en el contexto logístico permite evaluar el sector portuario en Brasil.

Palabras clave: *Eficacia; Logística; Puertos; Maíz; Productividad.*

1. INTRODUCTION

Ports are strategic links in global logistics chains, serving as transshipment points between maritime transport and land-based modes. According to Notteboom and Rodrigue (2008), indicators such as berth time and unberth time are fundamental for evaluating the operational efficiency of a port terminal. In Brazil, the "Brazil Cost"—which includes tax burden, bureaucracy, and deficient infrastructure—can extend the time ships remain at berths by up to 30%, directly affecting export competitiveness (Souza; Silva, 2015).

According to Falcão and Correia (2012), port infrastructure is a fundamental pillar of economic development and national competitiveness. The authors emphasize that continuous investments in the modernization and expansion of ports – through the expansion of berths, implementation of advanced technologies, and improvement of physical facilities – are essential to reduce operational costs and increase logistical efficiency. This evolution facilitates the integration of terminals with global supply chains and enhances the capacity to respond to the challenges of international trade, generating opportunities for the logistics and transportation sector.

Furthermore, coordination between port agents (shipowners, terminal operators, customs agents, and carriers) can optimize ship flow, minimizing berth idle time and speeding up undocking. Wilmsmeier et al. (2017) point out that integrated information systems can increase the efficiency of these processes by up to 15%. In the Brazilian context, implementing the Single Window for Foreign Trade promises to expedite customs clearances, helping reduce berthing and unberthing times.

Given this scenario, our project's main objective is to measure berthing and unberthing times at the main Brazilian ports. Using historical operational data, Pires (2016) defines port infrastructure productivity as the ratio between observed production and maximum production, or the ratio between the minimum quantity necessary for production and the quantity actually used. This definition is fundamental to understanding the modeling proposed in this project.

The objectives defined for this project include:

- 1) Collect operational data from the main Brazilian ports regarding corn handling, creating a data viewer and integrating databases available on the ANTAQ (National Agency for Waterway Transportation) portal.
- 2) Create a ranking of the top 10 Brazilian ports in corn handling based on average operational volume and the DEA method.
- 3) To show the evolution of the Port of Santos in the handling of corn between the years 2019 and 2023.

2. RATIONALE FOR THE ANALYTICAL METHODS AND TECHNOLOGIES USED

This chapter describes the theoretical basis for the analytical methods used in this project, as well as the main information technologies employed in processing

and analyzing the data.

2.1 Data Envelopment Analysis

Data Envelopment Analysis (DEA) is a modeling process that evaluates the relative efficiency of production units, known as Decision Making Units (DMUs). To do so, DMUs must perform the same activities; that is, they must be similar in the resources they employ and the activities they perform. The DEA method allows efficiency to be evaluated in two different ways: with an input orientation, which aims to minimize production factors (inputs) while maintaining a fixed level of production; and with an output orientation, which seeks to maximize the level of production while keeping inputs fixed (Cavalcante, 2011; Cavalcante; Leite, 2013).

Chaves and Thomaz (2008) note that DEA is a relevant technique for supporting managerial decision-making, as it allows evaluation of alternative scenarios based on best practices identified through mathematical modeling. Thus, this modeling and evaluation technique enables the selection of best practices while accounting for multiple criteria established a priori (Cavalcante; Andriola, 2012).

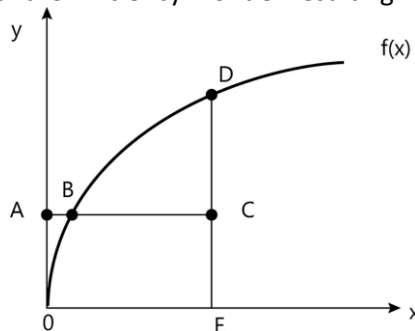
This technique originated in Farrell's (1957) studies, in which he proposed an innovative method for estimating process efficiency. Subsequently, Charnes, Cooper, and Rhodes (1978) continued Farrell's studies, operationalizing a method for estimating efficiency, which they called Data Envelopment Analysis.

Cavalcante and Leite (2013) and Chaves and Thomaz (2008) highlighted that since the emergence of the DEA method, several models have been introduced to its original version, specifically, the CCR model (Charnes; Cooper; Rhodes, 1978) which has as its main property the proportionality between inputs and outputs on the frontier, that is, an increase in the quantity of inputs will cause a proportional increase in the value of outputs; the BCC model (Banker; Charnes; Cooper, 1984 apud Cavalcante; Leite, 2013) or VRS (*Variable Returns to Outputs Scale*), which represents a variable return to scale and can encompass both input and output orientations. Regarding this model, Rosano- Peña (2008, p. 94) emphasizes that it "forms an efficient convex frontier with the best units, regardless of the scale of operation, and thus 'envelops' the inefficient units for each scale of production".

Therefore, the DEA technique allows for the estimation of the relative efficiency of production units through a comparison between the analyzed units (DMUs), in order to identify the most efficient ones, that is, those that achieve the highest productivity given the resources available to them. This means these DMUs have reached the desired 100% efficiency and, therefore, the efficiency frontier, represented by a score of 1 ($\rho = 1.0$), while the others were considered less efficient. However, the methodology indicates that these units could improve their efficiency by mirroring their benchmarks.

The potential of the DEA methodology, specifically the estimation of an efficiency frontier where efficient units are located, is illustrated by Souza Júnior and Gasparini (2006) in Figure 1.

Figure 1 - Representation of the Efficiency Frontier resulting from the use of DEA.



Source: Souza Júnior and Gasparini (2006)

2.2 DEA Applied to the Port Sector

Several published studies have used the DEA method in different contexts within the port sector. Vieira et al. (2014) conducted a comparative evaluation of container terminal efficiency in ports in southern Brazil using DEA. The inputs considered included draft, berth length, static capacity, and number of cranes, while the outputs were the number of ships, container handling, and productivity. Applying DEA identified efficient and inefficient terminals, providing valuable information for decision-making in the ports studied.

Acosta et al. (2011) conducted a study to identify benchmarks in Brazilian ports using DEA. The analysis considered relevant inputs and outputs in the port cargo handling process. The ports of Areia Branca (RN), Itaqui (MA), Natal (RN), Santos (SP), and São Francisco do Sul (SC) were identified as efficient, standing out for their resource optimization and modernization.

Giacomin (2019) analyzed the relative efficiency of 27 Brazilian solid bulk terminals, including coal importers, iron ore exporters, and soybean exporters, using DEA. Four inputs and two outputs were adopted in the analysis. The results showed greater efficiency in export terminals than in import terminals.

Garcia et al. (2017) analyzed the efficiency of waste generation in general cargo port terminals using the output-oriented DEA BCC model. The overall analysis identified eight efficient terminals, with DMU 18 standing out as having the highest value in the Normalized Composite. Pairwise analyses revealed DMU 21 as efficient in all analyses.

Vargas's (2020) research evaluated the efficiency of 19 container terminals in Brazil, responsible for 92.4% of port container traffic in 2018, using the DEA method. The study considered six inputs, such as the number of cranes and terminal area, and one output: annual throughput in TEUs. The analysis identified efficient and inefficient terminals, providing insights into operational improvements.

3. DATA ANALYSIS

This analysis is based on data collected and analyzed from the National Agency for Waterway Transportation (ANTAQ), covering the period from 2019 to 2023.

To process and consolidate this information, Python tools were used to standardize, filter, and integrate the data efficiently. As a result, a final structured file was generated, suitable for applying the Data Envelopment Analysis (DEA) method (Figure 2).

Figure 2 - Flowchart for analysis



Source: Authors (2025)

3.1 Data Collection

The data collection was carried out through ANTAQ. To access it, enter the ANTAQ portal and look for the section called "Waterway Statistics". On that page, you will find statistical data on Brazilian ports, organized by the agency.

For this study, data from the period 2019 to 2023 were used, as these years had complete records, ensuring the integrity and reliability of the database used in the research.

The files needed for processing the information were "Mooring" and "Cargo," both available in the same section of the ANTAQ website mentioned earlier.

After downloading, the files are available in ".txt" format, with names such as "2019Carga.txt" or "2020Atracação.txt". To facilitate data processing, the ".txt" extension was manually converted to ".csv", making them compatible with tools such as Microsoft Excel and other data analysis platforms. This procedure was applied to all files used in this research.

3.2 Data processing

Anaconda was used as the development environment for creating and running the Python code used to process the data in this study. The first step involved importing the libraries needed for data manipulation, analysis, and visualization. In the Anaconda environment, the import command loaded the Pandas, NumPy, Os, and Matplotlib libraries. The code snippet corresponding to this step is shown in Figure 3.

For manipulating and analyzing structured data, the Pandas library was used. According to MCKINNEY (2017), the library's creator, Pandas offers data structures such as DataFrames that allow easy reading, organization, filtering, and aggregation of large volumes of data and are effective for handling tabular data from CSV files, Excel spreadsheets, and relational databases.

Figure 3 - Importing libraries

```
•[1]: import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import os
|
```

Source: Authors (2025)

The NumPy (Numerical Python) library, according to OLIPHANT (2006), supports vectors, matrices, and a wide range of high-performance mathematical operations. Because of its performance, it underpins several other libraries, including Pandas, and is essential for numerical calculations, linear algebra, and statistical transformations.

The OS module, part of the Python standard library, automates file-system tasks. As documented by the Python Software Foundation (nd), this module enables interaction with the operating system, allowing operations such as manipulating directories, file paths and environment variables, as well as renaming, moving or listing files, which contributes to the organization and automation of processes.

Finally, the Matplotlib library was used to generate graphical visualizations, allowing the creation of static, animated, and interactive graphs. According to HUNTER (2007), Matplotlib is used in reports and dashboards and supports various visualization types, such as line graphs, bar graphs, scatter plots, and histograms.

3.3 Data processing

After data collection, data processing began, standardizing specific columns in the "2019Atracacao.csv" file. The columns "Arrival Date", "Bearing Date", "Operation Start Date", "Operation End Date", and "Unberthing Date" were converted to the standard date and time format "%d/%m/%Y %H:%M" (day/month/year hour: minute). This standardization was fundamental to enabling temporal calculations between the different stages of the port process.

Next, four new columns were created based on arithmetic operations between the mentioned dates:

Waiting Time for Docking: calculated as the difference between the docking date and the arrival date, indicating how long the ship waited to dock at the port.

Waiting_Operation: Calculated as the difference between the operation start date and the berthing date, representing the waiting time until loading or unloading begins.

Operation: Total time of the port operation, calculated by the difference between the end date of the operation and the start date.

Waiting_for_Undocking: Difference between the undocking date and the end-of-operation date, indicating how long the ship remained docked after activities ended.

In the file "2019Cargas.csv", I applied filters to the data of interest. First, the

"CDMercadoria" column was filtered for the code "1005", which corresponds to corn under HS4 classification. Subsequently, the "Sentido" column was filtered, selecting only the records classified as "Embarque", that is, export operations. Finally, a filter was applied to the "STNaturezaCarga" column, keeping only the records with the value "Exclusiva", which indicates that the ship was transporting exclusively corn.

For cases with duplicate records in the "IDAtracacao" column in the cargo file, an aggregation procedure was implemented to sum the values in the "VLPesoCargaBruta" column, ensuring data consistency with the total volume loaded per berthing.

After processing the files individually, the databases "2019Cargas.csv" and "2019Atracacao.csv" were integrated using the common key "IDAtracacao", resulting in the unified database called "dados_antaq".

Based on this consolidated database, the column "t/h – Operational Chart" was created as the ratio of gross load value (VLPesoCargaBruta) to operating time (Operação), representing operational productivity in tons per hour.

We repeated this process for 2019 to 2023, using the same treatment and integration criteria. In the end, only the columns of interest were selected for analysis, namely: 'Year', 'IDAtracacao', 'CDMercadoria', 'Port of Abertura', 'Port Complex', 'Type of Navigation of Abertura', 'Waiting_for_Abertura', 'Waiting_for_Operação', 'Operação', 'Waiting_for_Undocking', 'Nature of Cargo', 'VLPesoCargaBruta', 't/h – Operational Plank', 'IDBerco', 'Direction', 'STNaturezaCarga'.

Finally, after processing and consolidating the database, the final file used to apply the Data Envelopment Analysis (DEA) method was generated.

4. APPLICATION OF THE DEA

This research is a quantitative maximum efficiency study. Data from ANTAQ and related articles were used for data collection and development.

To construct the analyses, several steps were taken to structure and visualize the data, as follows:

- Separation of historical series data via pivot table;
- Survey of the number of berths per port, which will be used as input;
- Perform the average plank casting by port;
- Begin comparisons with the top 10 ports of 2019;
- Create a table with the following data: ports, number of berths, and average plank height, considering the last two as input and output, respectively.
- Creating the variables V1 and U1 using Solver.
- Creating weighted input, weighted output, and function.
- Data entry into the solver.
- Restrictions: Variable cells ≥ 0 ; weighted input = 1 (total capacity) and function ≤ 0

- After entering the data, change the solution method to "LP Simplex" and click "Solve".

Next, to analyze the efficiency of the 10 ports in Brazil (UF), we collected information from a list containing historical data from 2019 to 2023. To evaluate port efficiency using the average operational rate, we used Data Envelopment Analysis (DEA).

According to Charnes et al. (1978), Data Envelopment Analysis (DEA) is a non-parametric methodology that allows evaluating the relative efficiency of decision units, considering multiple inputs and outputs, without the need to specify a production function.

The decision to use the DEA method for analyzing port efficiency through average boarding, comparing ports, was applied to 10 ports. The input 1 and weighted input were the number of berths in each port multiplied by the weights assigned to each input, respectively. The output and weighted output were the average operational boarding and the average operational boarding minus the weight assigned to each output, respectively. The number of DMUs was defined as the 10 ports in Brazil (UF). Table 1 represents the defined variables.

Table 1 – Model variables

DMU	The 10 ports in Brazil (State)
<i>Input 1</i>	Number of berths at each port
<i>Weighted input</i>	Number of cradles x variations in weights assigned to each <i>Input</i>
<i>Output 1</i>	Medium operational plank
<i>Weighted output</i>	Average operational plan – the weight assigned to each <i>output</i> .

Source: Authors (2025)

4.1 Results

Based on the analyses performed, summary tables were developed presenting the results obtained. Figure 3 presents the efficiency results for 2019 and 2020, with the following tables broken down by year and by port evolution. Based on the collected data and the modeling, among the 10 main corn handling terminals, Hidrovias do Brasil Miritituba showed the highest efficiency compared with other Brazilian port structures. Santos, which handles a significant volume of corn, achieved only 43% efficiency in 2019, increasing to 67% in 2023. Chapter 4.2 presents the construction of a Power BI dashboard for port operation time analysis and complements the operational analysis.

Figure 3 – Example of a comparison of ports in the years 2019 and 2023

Ano 2019			Ano 2023		
Ranking	Portos	Eficiência Máxima	Ranking	Portos	Eficiência Máxima
1	Hidroviás do Brasil Miritituba	100%	1	Cargill Agrícola S.A. (ETC Miritituba/PA)	100%
2	Terminal Graneleiro Hermasa	80%	2	Hidroviás do Brasil Miritituba	97%
3	Itaqui	75%	3	Terminal Graneleiro Hermasa	68%
4	Terminal de Expedição de Grãos Porto Chuelo	71%	4	Santos	67%
5	ETC Miritituba	57%	5	ETC Miritituba	67%
6	Estação Cujubinzinho	45%	6	Terminal de Expedição de Grãos Porto Chuelo	58%
7	Santos	43%	7	São Francisco do Sul	56%
8	Estação Cianport Miritituba	30%	8	Estação Cianport Miritituba	53%
9	Santarém	20%	9	Estação Cujubinzinho	30%
10	Terminal Vila do Conde	14%	10	Santarém	8%

Source: Authors (2025)

4.1 4.2 Data analysis in *Power BI*

The research generated a consolidated file with ship and cargo data, which was imported into Power BI to generate analytical visualizations and clarify port operational dynamics.

The dashboard displays average berthing, operating, and unberthing times.

Berthing waiting time is the average interval between a ship's arrival and its berthing; operating time is the average duration of corn unloading; and unberthing waiting time is the average interval between the end of unloading and release for departure.

Figure 5 highlights the indicators by berth, enabling comparisons across terminals and supporting strategic decisions by highlighting locations with the highest operational efficiency.

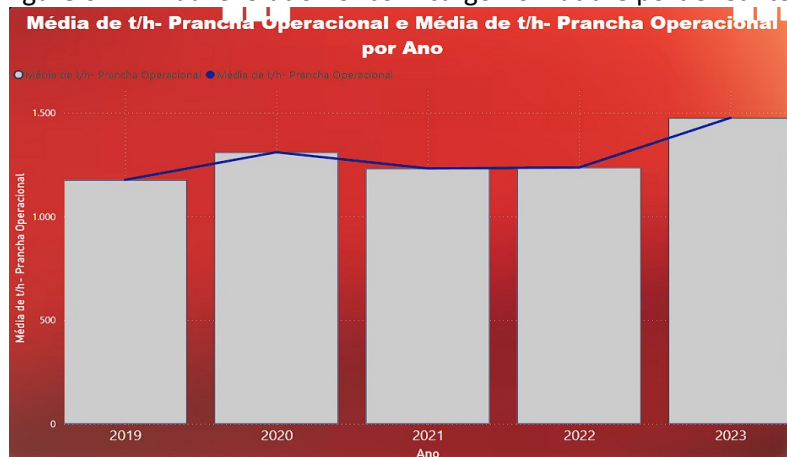
Figure 5 – Visualization of operating time



Source: Authors (2025)

Figure 6 compares the Port of Santos's corn unloading productivity from 2019 to 2023, which increased from 1,176 t/h to 1,475 t/h, indicating technological, structural and logistical improvements and consolidating its efficiency for cargo flow.

Figure 6 – Annual evolution of corn cargo flow at the port of Santos



Source: Authors (2025)

Figure 7 demonstrates the operational efficiency of port complexes, considering handling capacity and utilization rate, which made it possible to identify bottlenecks and opportunities for expansion. Operating at 100% capacity may indicate the need for investments in infrastructure, technology, and management. In the efficiency ranking, Cargill Agrícola SA and Hidrovias do Brasil led, with utilization rates of 100% and 97%, respectively.

Figure 7 – Ranking of port complex efficiency for corn shipping.



Source: Authors (2025)

5. FINAL CONSIDERATIONS

This work presented the concepts of operational efficiency and the application of Data Envelopment Analysis (DEA) in ports, emphasizing the average operational rate as a performance indicator, along with the integration of analytical methods and technological tools (Python and Power BI).

ANTAQ's automated data collection and processing method, combined with data analysis using Python's Pandas library, ensured consistent, high-quality information and enabled the generation of accurate indicators that reflect the operational reality of the ports analyzed.

The BI interface enabled evaluation of operational data from the ports selected for analysis. Cargo handling increased between 2019 and 2023, demonstrating the consistency and relevance of Brazilian corn production and exports.

Finally, the practical application of DEA, combined with the construction of Power BI dashboards, classified the main Brazilian ports by corn-handling productivity, identified bottlenecks, and provided strategic input for continuous improvement in logistics efficiency.

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