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Shipping Patterns at the Port of Sines: A Temporal Analysis from 2010 to 2023

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Abstract: This study focuses on an analysis of the dwell time of vessels in the Port of Sines jurisdiction area, between 2010 and 2023, as an indicator of operational efficiency, with the objective of analyzing the temporal patterns of vessel movements at the Port of Sines, aiming to understand how efficient the operations are. This research will enable the extraction of meaningful patterns from temporal data and the addressing of potential bottlenecks, enabling smother operations and optimized performance. A total of 157,515 records of vessel movements were analyzed using statistical modeling in Python (version 3.11.8). The overall average dwell time calculated for these 13 years was 0.55 days, for a medium number of port calls per year of 2199. This result highlights the operational efficiency of the Port of Sines, although the variability between the different terminals remains significant. The Multipurpose Terminal registered the longest dwell time (1.08 days), especially due to the diversity of cargo handled. In contrast, the Container Terminal had an average dwell time of 0.38 days. Anchoring frequency has emerged as critical for optimization. The implementation of just-in-time principles is proposed as a strategy to reduce anchorage times, enhance coordination and collaboration within the operational chain, and mitigate greenhouse gas (GHG) emissions. Notwithstanding the efficiency attained at the Port of Sines, this study suggests that further enhancement of its operational efficiency is feasible and desirable. This would contribute to the sustainability agenda and reinforce the port's position in the global trade landscape.

Keywords: port efficiency; port operations; dwell time; maritime industry; emissions

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1. Introduction

Since the 1950s, there has been considerable expansion in world trade, which currently accounts for over 50% of global economic output [1]. This development has increased the importance of maritime transport, assuming a central role in facilitating international trade in the contemporary global economy. It is therefore vital to improve knowledge about the role of ports within the transportation system, which function as pivotal hubs that connect maritime routes with inland networks. Ports facilitate domestic and international trade by enabling supply chains and promoting the global connectivity of goods, significantly contributing to economic development.

According to reports from the International Maritime Organization (IMO), maritime transport is responsible for over 80% of world trade, which accounts for approximately 2.9% of global greenhouse gas (GHG) emissions [2,3]. This has led to growing concern regarding measures that can be implemented to reduce these emissions and enhance energy efficiency. Since the debate around global greenhouse gas emission reduction in ports arose and gained prominence in 2017, the time that vessels spend at ports has emerged as a means to reduce emissions [4]. Despite this time being relatively brief compared to time spent at sea, inefficient port operations can cause port congestion and disrupt intermodal logistics, increasing costs and environmental impacts.

In essence, vessel dwell time signifies the duration a vessel spends at a port, encompassing activities such as cargo handling and routine procedures. That is to say, it denotes the time interval between a vessel's entry to and exit from the port. The occurrence of extended dwell times is frequently attributed to factors such as inadequate coordination among stakeholders, inefficient scheduling, and unanticipated operational challenges. These circumstances can result in protracted docking waiting periods and congestion issues [4,5]. These delays also have implications for the environment, given the increases in fuel consumption and greenhouse gas emissions that they entail [6–8].

The United Nations Conference on Trade and Development (UNCTAD) has calculated, using MarineTraffic data, that ships in the 25 largest global economies spend an average of 1.16 days in ports [8]. The present study benchmarks the average vessel dwell time at the Port of Sines against the United Nations Conference on Trade and Development's estimated figures for ports in the world's largest economies. This comparison highlights the Port of Sines's efficiency and identifies areas for further improvement. By integrating these methods, this study provides a detailed analysis of dwell time within each port zone, offering insights into efficiency levels and pinpointing operational challenges.

One way to improve performance could be through the implementation of strategies such as just-in-time (JIT) arrivals, which could help to address several challenges associated with port operations. The JIT approach, originally developed during the 1960s and 1970s as a strategy to optimize supply chain management, aims to synchronize production and inventory processes with real-time consumer demand, thereby ensuring that vessels operate at optimal speeds and arrive at port terminals when facilities and services are fully available [9]. The adoption of JIT practices has been shown to yield substantial environmental and operational benefits. For instance, it enhances environmental sustainability by reducing emissions and fuel consumption, with savings estimated to range from 2% to 20% [9–11].

In the implementation of JIT, an essential component is effective communication, as it enables the vessel's commanding officer to receive timely updates on the availability of port services and facilities, facilitating the adjustment of the vessel's speed to align with operational requirements [10]. Additionally, the successful execution of JIT strategies requires coordinated efforts among vessel operators and all port service providers to manage arrival schedules effectively. However, achieving these outcomes requires robust coordination and collaboration among all stakeholders in the maritime operational chain [12].

Despite the fact that a number of studies have been performed in order to assess and enhance port efficiency, including data envelopment analysis (DEA), stochastic frontier analysis (SFA), ordinary least squares (OLS) regression, analytic hierarchy process (AHP), and directional distance function (DDF) studies, there is a paucity of research focusing on the evaluation of vessel dwell times across distinct operational zones within a port, including their movement through the vessel traffic service (VTS) area from entry to departure [13–22]. Therefore, this document will address the referenced research gap through a detailed analysis of vessel dwell time within distinct operational zones of a port. Understanding these temporal patterns is crucial for improving traffic flow, optimizing dock allocation, and enhancing overall port efficiency. This will allow for the bridging of this gap, offering insights that are particularly valuable for port authorities, maritime operators, and policymakers.

In this context, this study analyzed the temporal patterns of vessel movements at the Port of Sines, Portugal, focusing on time management and navigation efficiency. The research aligns with the objectives of the NEXUS Agenda, which aims to develop and implement a smart berth system in this port [23]. The analysis of port efficiency is essential as it enables the optimization of operational performance, maximization of available resource productivity, and enhancement of operations even with limited resources [4].

This work will contribute to the objectives of the NEXUS Agenda, which focuses on the development and implementation of a smart berth solution at the Port of Sines. In particular, this document has the objective of analyzing how temporal patterns can significantly enhance port efficiency by identifying and understanding variations in port activities over time. Furthermore, insights derived from temporal data enable the prediction and mitigation of potential bottlenecks, such as extended cargo dwell times or vessel delays, thereby facilitating proactive decision-making. By optimizing operational workflows, this approach supports reductions in emissions, aligns with sustainability objectives, and improves overall productivity.

The remaining sections of this document will be structured as follows: First, Section 2 will outline the materials and methods employed for the bibliometric and data analysis, respectively. Subsequently, Section 3 will present and interpret the findings of the bibliometric analysis, followed by the results of the statistical data analysis. Finally, Section 4 will conclude with the key findings and considerations based on the obtained results and future research directions.

2. Materials and Methods

The present study employs bibliometric techniques combined with statistical analysis of vessel dwell times and evaluates efficiency at the Port of Sines. The subsequent section details the methodology, presenting the framework to measure temporal efficiency. The following illustration (Figure 1) displays the area and location of each of the studied terminals in detail.

Figure 1. Port of Sines terminals' locations.

2.1. Bibliometric Analysis

A bibliometric analysis was conducted to establish a robust theorical framework, examining extant research on port efficiency and vessel dwell time [24]. This approach ensures that this study is connected to the existing literature in maritime operations. The bibliometric analysis involved the following steps:

1. **Research Question Formulation:** The bibliometric analysis was framed around the following question: "How does vessel dwell time affect port efficiency?" This provided guidance in the selection of relevant publications and keywords.
2. **Data Collection and Keyword Extraction:** The search terms "port efficiency", "port operations", and "ship time" were entered into the Web of Science (WoS) database, resulting in the identification of relevant publications. This query yielded a corpus of research publications central to the topic.
3. **Keyword Co-Occurrence Analysis:** VOSviewer 1.6.20 software was utilized to analyze keyword co-occurrence, thereby creating a network of terms that frequently appear together. This co-occurrence analysis reveals thematic clusters within the research, highlighting key areas such as port efficiency, emissions, and just-in-time arrival.
4. **Data Organization:** publications that met the inclusion criteria were organized with EndNote software (version 21.3), allowing for the systematic tracking of sources.

Initially, 1676 documents were identified in the Web of Science database for inclusion in this study. However, in order to improve the quality and comprehensiveness of the study, additional sources of information were added. To this end, documents from various organizations and articles containing specific data not available in the previously found publications were examined, resulting in the identification of 21 supplementary studies from other databases, reaching a total of 1697 documents.

Once these were identified, a duplication analysis was carried out, but no duplicates were found. However, during screening, 454 records were excluded for being unrelated to the study theme, leaving a total of 1243 records. In order to ensure that all results were retrievable, a search was conducted to determine how many of these records were open access, and it was found that only 98 of them met the criteria, resulting in the exclusion of 1145 documents.

Finally, final restrictions were implemented in the records, which resulted in the exclusion from the Web of Science database of results that were not in Portuguese, Spanish, or English, in order to enable an understanding of the language of records, and the inclusion of only those that were articles, as these represent significant peer-reviewed scientific contributions [25]. This resulted in the exclusion of 8 and 55 documents, bringing the final number of WoS articles retrieved to 14. With regard to the other databases, results that did not have all the necessary information, such as the author or date, were excluded, resulting in the exclusion of 3 records. This process resulted in 32 records being included in the study.

To ensure transparency and replicability in the document selection process, a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA diagram) was employed (Figure 2). This diagram, retrieved from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) website, and adapted to the authors' needs, provides a detailed overview of the document selection workflow, systematically illustrating the number of articles and documents considered, excluded, and retained at each stage of the study's methodology [26–28].

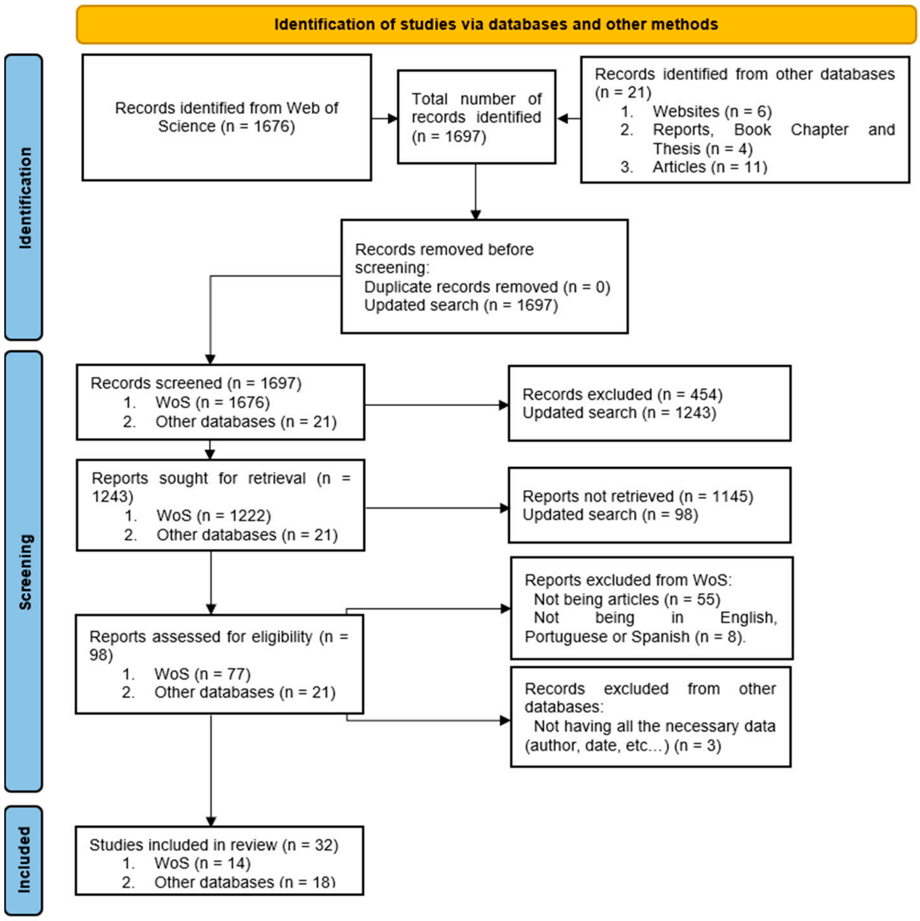

Figure 2. PRISMA flow diagram.

It is important to note that despite other records being used in the document and present in Figure 2, the bibliometric analysis was conducted exclusively on scientific articles that are based on the theme.

2.2. Data Collection, Pre-Processing, and Statistical Analysis of Vessel Dwell Time

Data concerning vessel movements at the Port of Sines were provided by the Administration of the Ports of Sines and Algarve, S.A. (APS). Information was retrieved from two databases: the Single Port Window (2010–2021) and the Logistics Single Window (2021–2023). The sampling period arises from the data availability at the Port of Sines for the movements analyzed, since the digital port management system was implemented in 2009. Data for the years 2009 and 2024 were not complete but were important for identifying the ships that arrived in 2009 and 2023 and left in 2010 and 2024, respectively. The analyzed datasets comprise detailed timestamps and descriptions for every vessel movement, including events such as entry, docking, anchoring, and departure. The analyzed data movements are presented in Table 1, with the corresponding meaning, enabling better comprehension of the analyzed data.

Table 1. Glossary of each vessel movement.

Glossary—Analysis of Ship Movement Data	
PLF—Entry	Entry of the vessel into the maritime port's jurisdiction area.
Anchoring	Anchoring of the vessel in the anchorage areas.
Exit to Holding Area	Leaving the port area to wait for docking.
Approach from Holding Area	Entry into the port area to dock after hovering.
Anchoring Suspension	Weighing of the anchor for departure in order to dock.
Docking	Docking of the vessel into the terminal and cargo loading/unloading.
Leaving	Departure of the vessel from the terminal.
PLF—Exit	Exit of the vessel from the port's maritime jurisdiction area.

Figure 3 presents the most recurrent paths that vessels take after entering the port jurisdiction area. Through analysis, we can observe that vessels can follow three different routes: docking immediately after entering the port, which would be the most efficient way, anchoring in the anchorage areas, or leaving the port jurisdiction and waiting to dock. The last two options keep the main engine running, so emissions are maintained even when the vessel is stationary. In most cases, anchoring and hovering are the result of the port's inability to receive the vessels at the terminals or the earlier arrival of the vessels.

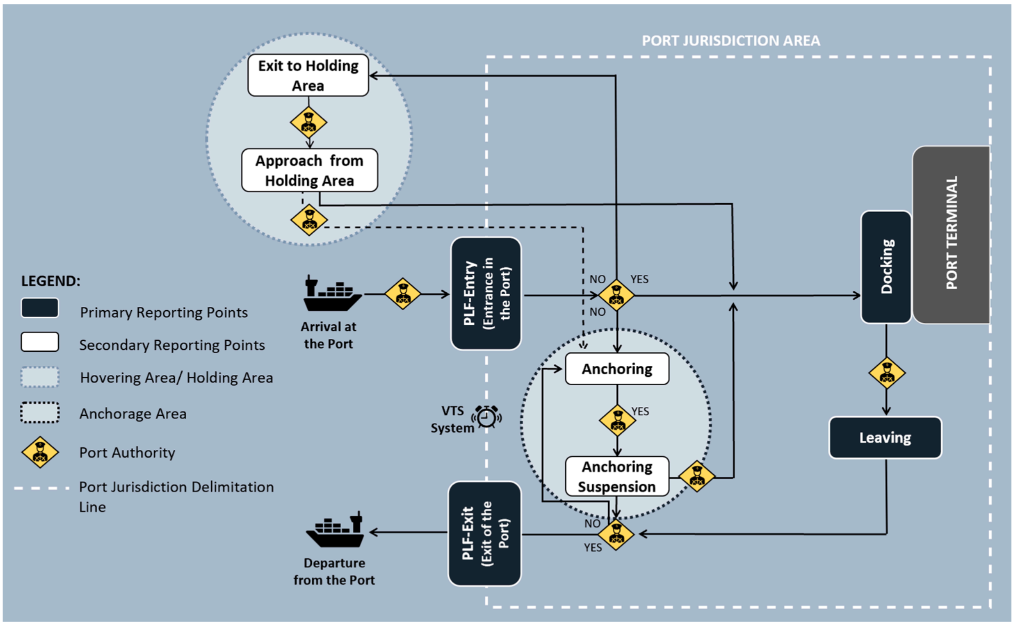

Figure 3. Paths that vessels may take upon entering the port.

A pre-processing procedure was applied in order to ensure the accuracy of the data, according the following steps:

- **Data Quality Check:** the raw data were examined to remove duplicate records, address missing values, and rectify inconsistencies in timestamps.
- **Categorization of Movements:** Vessel movements were categorized into specific stages, including entry into port jurisdiction, anchoring, docking, and exit from port

jurisdiction. This categorization enabled a clear understanding of each maneuver's duration within the port.

- **Data Curation:** movement records were curated to filter out incomplete records and ensure that only verified data points were included in the analysis.

The analysis of vessel dwell time and movement was performed using the Python programming language in a Jupyter Notebook environment (version 6.4.12), with a focus on descriptive statistics to capture average times across different stages and terminals. This methodological approach yielded a comprehensive perspective on time efficiency within the port's jurisdiction, using the scale of the vessels instead of the IMO, since the scale changes between voyages and the IMO scale stays the same. The research proceeded according to the following steps:

- **Mean Dwell Time Calculation:** for each terminal (Liquid Bulk Terminal, Petrochemical Terminal, Multipurpose Terminal, Liquified Natural Gas Terminal, and Container Terminal), the average dwell time was calculated based on vessel turnaround data, allowing for a terminal-specific comparison of time efficiency.
- **Maneuver Duration Analysis:** Each maneuver was analyzed to determine its average duration, by calculating the time difference between the start date and time of a maneuver and the start date and time of the next maneuver, based on JUP and JUL data. Furthermore, the data were examined to identify changes in operations from 2010 to 2023.
- **Anchoring Analysis:** given the established correlation between anchoring and dwell time, a focused analysis was conducted on anchorage patterns, particularly at the Liquid Bulk Terminal, where the majority of anchoring events occurred.
- **Outlier Analysis:** the outliers for each terminal were analyzed to assess both their quantitative impact on the results and their overall frequency.

3. Results and Discussion

3.1. Bibliometric Analysis Results

As can be observed in Figure 4, which illustrates the evolution of publications over the years, it is evident that the theme has gained prominence since 2018, which, along with 2023, was the year with the most publications. Prior to this, the total number of publications was only three.

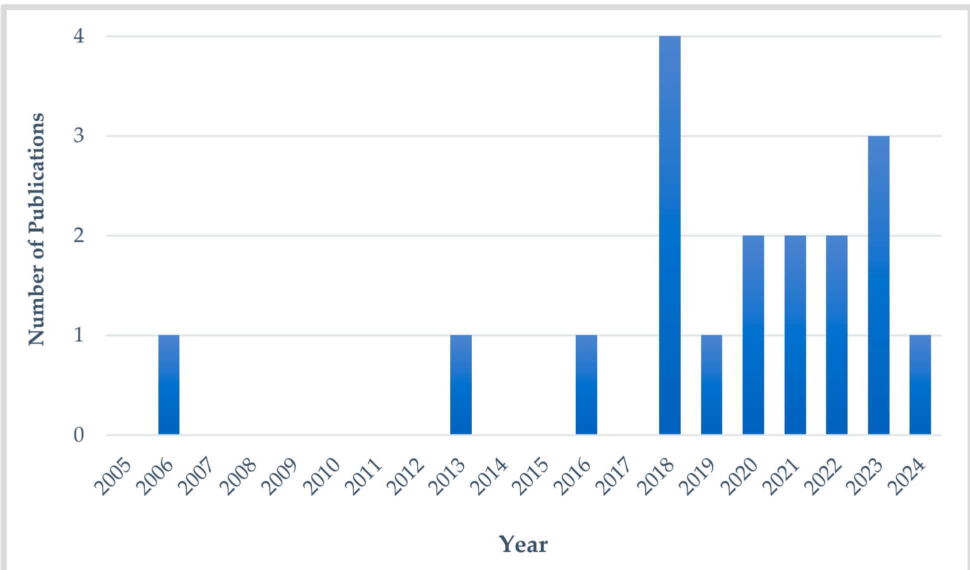

Figure 4. Number of publications between 2005 and 2024.

Figure 5 displays the number of citations accrued by each publication retrieved. This enables the identification of the most relevant articles based on their citation frequency. In this instance, the number of citations was retrieved from both Web of Science and Google Scholar, in accordance with the database where the article was located. A subsequent analysis of the figure reveals that over a third of the articles have accrued more than 20 citations, with a select few having amassed over 50 citations. The article with the highest number of citations is "Data Envelopment Analysis (DEA) and Improving Container Port Efficiency" by Cullinane and Wang, with 170 citations.

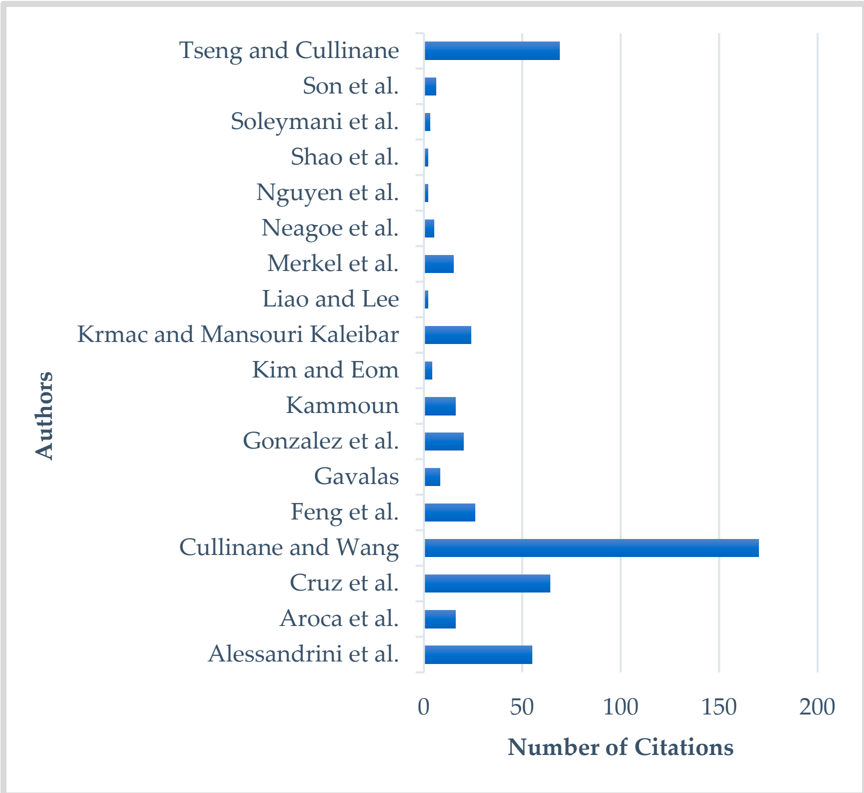

Figure 5. Number of citations for each of the studied publications [2,3,5–7,9,11–22].

A comprehensive visualization of the global distribution of publications across continents is provided in Figure 6, offering valuable insight into the research activity of different regions concerning this specific area. The figure was made through the software QGIS Desktop (version 3.36.3) The numbers are based on the country where the institution affiliated with the corresponding author is located. There is at least one publication associated with each of the populated continents. Nevertheless, Asia and Europe prevail in terms of publications, with eight and nine publications, respectively.

The global distribution of publications across continents enabled an analysis of the regions most invested in this type of research. It is noteworthy that the continents with higher publication volumes tend to be home to larger ports, which are more likely to encounter greater challenges related to port efficiency.

In the VOSviewer analysis, a deep examination of the data reveals a correlation between concepts such as "port efficiency" and "emissions", thereby emphasizing the pivotal role that operational enhancements play in reducing the ecological impact of port activities. By optimizing processes, ports can achieve greater energy efficiency, minimize waste, and significantly reduce their carbon footprint, thereby demonstrating the intrinsic link between sustainability and efficiency in modern logistics and maritime operations.

The keyword cloud generated by VOSviewer highlights the increasing focus on sustainability in port operations (Figure 7).

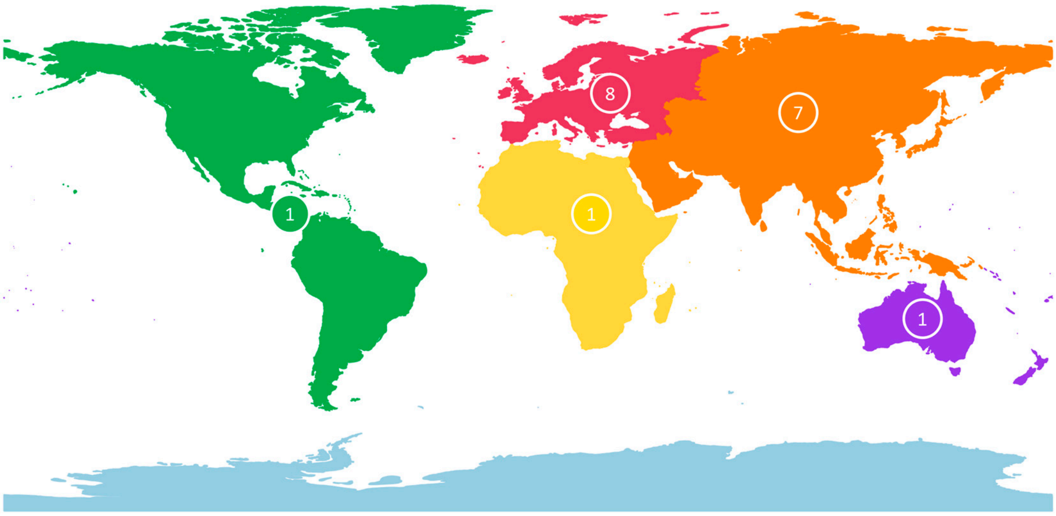

Figure 6. Global distribution of the studied publications.

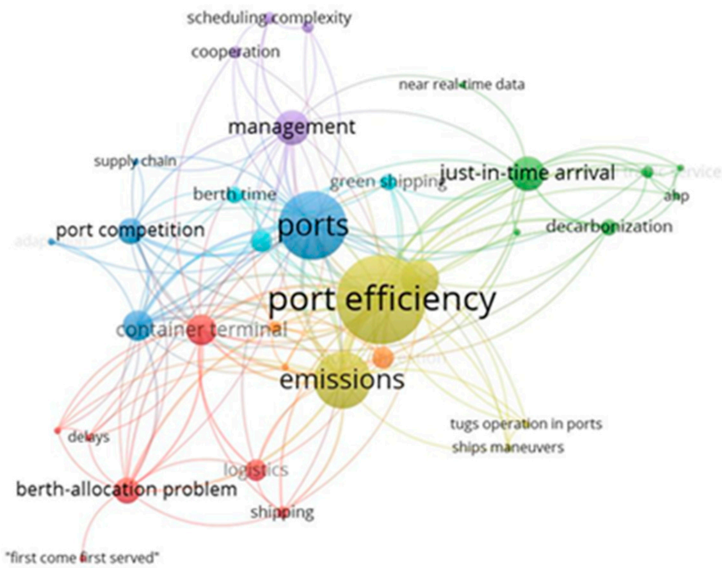

Figure 7. VOSviewer keyword cloud.

The VOSviewer-generated keyword cloud further corroborates the relevance of this study by highlighting key themes such as port efficiency, port-related emissions, and just-in-time operations. These findings underscore the investigation's relevance and its timely nature.

Based on the documents included in this study, dwell time, a crucial element that directly affects port operations and, in turn, port competitiveness, is intimately related to port efficiency. Cruz et al. point out that vessel turnaround time, which is fundamentally connected to dwell time, has a significant impact on maritime competitiveness [18]. This finding highlights the importance of time-based performance in port operations.

The possibility of using virtual arrival (VA) and port call optimization (PCO) in reducing fuel consumption and CO_2 emissions is investigated by Merkel et al. [11]. In a similar vein, Alessandrini et al. suggest utilizing historical AIS and LRIT vessel tracking data to improve resource allocation and ETA predictions while lowering vessel arrival uncertainties [22]. In this context, and according to Gonzalez et al. and Aroca et al., just-in-time (JIT) operations are intended to further align vessel schedules with port operations, which will lower costs and emissions and, consequently, improve efficiency [2,9]. These tactics are in line with approaches proposed by Cullinane and Wang, who affirm that in order to decrease operational bottlenecks, it is important to measure and optimize time-sensitive operations [13]. This method reinforces the value of time measures for assessing and enhancing port performance and supports studies on dwell time.

Feng et al. contribute to the assessment of the time efficiency of ship movements in marine ports, highlighting the importance of time-sensitive procedures to identify delays and inefficiencies [21].

The reviewed literature on port efficiency metrics, advanced technologies, and data-driven approaches offers a solid basis and aligns with the conducted bibliometric analysis, highlighting the interconnected nature of time optimization and overall port efficiency.

The various analyses conducted were fundamental to this study. Specifically, they facilitated the inclusion of recent publications containing the most up-to-date information available. The credibility of the study was enhanced by the incorporation of several articles that have attained a high standing within the scientific community.

3.2. Statistical Analysis of Vessel Dwell Time Results

In this study, a total of 157,515 records were analyzed, representing all the movements of the 29,567 vessels which entered the Port of Sines between 2010 and 2023. The total number of vessels that entered each terminal is shown in Figure 8. From the analysis, it can be seen that the Container Terminal handled the most vessels, with 13,553 vessels docking at this terminal, and the Liquified Natural Gas (LNG) Terminal handled the fewest number of vessels, with 649 port calls.

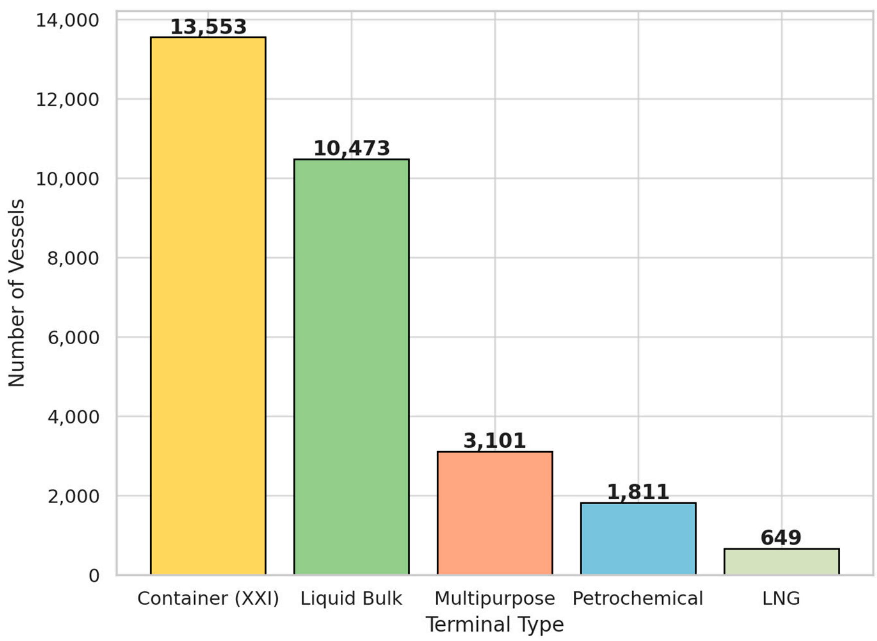

Figure 8. Vessel entrance distribution by terminal.

Figure 9 shows the total time spent on each maneuver during the considered period. In this case, the years 2009 and 2024 have been included due to the fact that some vessels entered the port in 2009 and 2023 and left in 2010 and 2024.

Figure 9. Evolution of maneuver duration between 2009 and 2023.

When analyzing the figure, it can be seen that maneuvers such as docking and anchoring have constant execution times between 2010 and 2023 and together account for a considerable portion of the total dwell time (>90%). In this case, the duration of anchoring maneuvers has increased since 2016, which may have been the result of developments in the Container Terminal. This is the maneuver for which evolution is most noticeable. The maneuver Completion of Mooring Reinforcement, which represents a specific action to enhance post-docking stability, was recorded only six times during the analyzed period. Due to its low frequency in relation to the total volume of the database, this maneuver was excluded from subsequent analyses.

Table 2 illustrates the different time metrics for each terminal and for the Port of Sines as a whole. More specifically, this table presents the percentage of vessels anchoring, the average times of anchoring and docking, and the dwell time in each location.

Table 2. Port operations summary: port calls, dwell times, and docking and anchoring metrics.

Terminal	Total Number of Port Calls (Total)	Average Number of Port Calls (per Year)	Average Dwell Time (in Days)	Average Anchoring Time Consumption (in Days)	Maximum Vessel Dwell Time (in Days)	Average Docking Time Consumption (in Days)	Percentage of Vessels That Anchor (%)
Liquid Bulk Terminal	10,473	748	0.59	0.19	11.85	0.38	60
Petrochemical Terminal	1811	129	0.55	0.18	16.67	0.35	46
Multipurpose Terminal	3101	222	1.08	0.35	349.17	0.69	20
Liquified Natural Gas Terminal	649	46	0.60	0.19	8.53	0.38	11
Container Terminal	13,533	967	0.38	0.12	598.83	0.24	18
Port Total	29,567	2112	0.55	0.18	598.83	0.35	38

Over the 13 years analyzed, the Port of Sines had an average dwell time of 0.55 days, including 0.35 days of docking time, which includes the loading and unloading of cargo. Despite the overall efficiency of the operation, vessels spend an average of 0.18 days at anchor, which represents 33% of their total time in the port's jurisdiction. This suggests that one-third of the time vessels spend in the port is spent at anchor.

The Liquid Bulk Terminal stands out with 60% of its vessels at anchor, the highest percentage among the port's terminals. However, the average anchorage time is 0.19 days, which is close to the port average. The terminal's total dwell time is 0.59 days, of which 0.38 days are spent on docking maneuvers. These results seem to indicate that despite frequent anchoring, the terminal maintains operational efficiency by balancing high anchorage rates with efficient procedures.

The Multipurpose Terminal has the longest average dwell and docking times of 1.08 days and 0.69 days, respectively. Although only 20% of its vessels anchor, those that do spend an average of 0.35 days at anchor, the longest among of all terminals. These results appear to highlight the challenges the terminal faces in managing different types of cargo, which have a significant impact on its overall efficiency.

The Container Terminal is the most time-efficient in the Port of Sines, with a total dwell time of only 0.38 days. Docking operations are completed in an average of 0.24 days, reflecting the terminal's high efficiency in cargo handling. Only 18% of vessels require anchorage, and those that do stay an average of 0.12 days (around 3 h). These metrics underscore the terminal's operational excellence and its ability to minimize delays.

The LNG Terminal handles the fewest vessels of any of the port's terminals, contributing to its excellent time metrics. Only 11% of vessels anchor, and while anchoring is rare, those that do stay longer than at other terminals. The terminal's dwell time averages 0.60 days, with docking accounting for 0.38 days, more than half of the total. Despite the low anchorage frequency, the long duration of docking, due to the fact that this type of cargo takes a considerable amount of time to load and unload, affects the overall time efficiency of the terminal.

At the Petrochemical Terminal, 46% of vessels are anchored, the second-highest rate among the terminals. These vessels spend an average of 0.18 days at anchor, in line with the port average. The terminal's total dwell time is 0.55 days, of which 0.35 days are spent docking. Although its performance is in line with port averages, the reliance on anchorage for almost half of the vessels highlights potential areas for improvement to increase overall efficiency.

Throughout the port, docking remains the most time-consuming operation as it includes both cargo handling and vessel mooring. While anchoring times have increased since 2021, there is some variability, with some vessels anchoring for short periods (e.g., 10 min) and others for longer periods (e.g., 2 days). This variability indicates ongoing challenges in time management and possibly highlights the need for targeted optimization in some of the terminals.

Table 3 presents port metrics without consideration of outliers, in order to observe the impact that these cases have on the results. Specifically, the table presents the maximum operation time for each of the terminals, the average dwell time without these vessels, and the percentage and number of outliers in each of the terminals separately and in total. It is important to note that in this study, outliers were automatically sorted by Tukey's Fences method [29,30].

Table 3. Time metrics in each terminal without outliers (in days).

Terminal	Maximum Vessel Dwell Time Without Outliers	Average Dwell Time Without Outliers	Number of Port Calls (Outliers)	Percentage of Outliers
Liquid Bulk Terminal	2.80	0.53	628	6
Petrochemical Terminal	3.10	0.44	163	9
Multipurpose Terminal	6.30	0.49	801	26
Liquified Natural Gas Terminal	1.42	0.53	25	4
Container Terminal	1.61	0.28	1267	9
Port Total	6.30	0.45	2884	10

As can be observed in Table 3, the inclusion of outliers significantly decreases the values of vessel dwell times across terminals. In total, 2884 outliers were identified, and several of them can be attributed to vessel-specific issues, in particular, vessels requiring major repairs. The reasons for the extended time taken by the outliers include delayed operations, inspections, repairs, vessels conducting work in the port area, and prolonged vessel clearance processes due to adverse weather conditions.

In terms of the outliers' vessel classification, considering all outliers, the majority are Oil Tankers, which sometimes go to more than one terminal during their stay at the port, and Container Vessels, which are vessels that more frequently enter the port. On the contrary, vessels with a dwell time superior to ten days are not of a dominant type, being, for example, Livestock Carriers, Bulk Carriers, General Cargo Carriers, and Container Ships.

As mentioned earlier, when outliers are not considered, we can notice a significant reduction in dwell time across the terminals, especially at the Multipurpose Terminal, which is no longer the terminal with the highest dwell time. The Container Terminal also experiences a decrease in dwell time, strengthening its position as the most efficient terminal.

In terms of outlier percentages, only the Multipurpose Terminal presents an outlier rate exceeding 10%, with 26%. This finding shows the impact that outliers have on dwell time at this terminal. The remaining terminals' results align more closely with the expected operational performance, without any unexpected deviations.

At a port-wide level, the exclusion of outliers reduces the average dwell time at the port by 0.10 days, making the dwell time 0.45 days. Overall, 10% of the vessels entering the port are classified as outliers, a percentage that can be considered a satisfactory metric for operational analysis.

Table 4 provides a detailed comparison of port performance worldwide, highlighting the best- and worst-performing ports in various cargo categories within the top 25 economies. This comparison serves as a benchmark to evaluate the Port of Sines against some of the largest and most important ports in the world. It also illustrates the disparity in the volume of port calls between Sines and these larger ports, highlighting why the efficiency of Sines cannot be directly compared with that of its international counterparts. It is important to note that the countries that have the best metrics in each category are in green, and those with the worst metrics are in red.

Table 4. Best- and worst-performing countries in terms of each type of cargo (in days). Data source: United Nations Conference on Trade and Development (UNCTAD), 2019 [8].

Country	Number of Port Calls	Liquid Bulk	Dry Bulk	Containers	Break Bulk	Liquified Natural Gas	Liquified Petroleum Gas	Average
Japan	180,400	0.31	0.90	0.35	1.12	0.99	0.32	0.67
USA	72,485	1.64	1.84	1.00	1.79	1.28	2.03	1.60
Singapore	60,712	0.60	0.12	0.77	0.65	2.22	1.12	0.91
Norway	49,339	0.61	0.87	0.33	0.34	0.32	0.75	0.54
Turkey	47,488	1.11	4.00	0.63	1.52	1.31	1.36	1.66
Brazil	27,546	1.74	2.67	0.81	2.45	2.94	1.66	2.05
Canada	27,225	1.12	0.32	1.49	0.28	-	-	0.80
Sines	2042	0.59	1.08	0.38	1.08	0.60	0.55	0.55
Total	1,884,818	0.94	2.05	0.70	1.11	1.11	1.02	1.16

From a global perspective, the Port of Sines demonstrates an impressive average dwell time of 0.55 days. This performance is notably lower than the global average of 1.16 days reported in 2020 by UNCTAD for the world's 25 largest economies. However, it is important to contextualize these findings by considering the characteristics of the port. Sines is a medium-sized facility that handles a relatively low volume of vessel traffic compared to major international ports. These factors contribute significantly to its favorable time metrics. Nonetheless, the results validate the port's operational excellence while highlighting the importance of placing its performance in the broader context of global port operations.

In this case, we may imply, through the analysis of the obtained results, that the anchoring rates would benefit from the implementation of just-in-time arrivals in the Port of Sines. Anchorage reduction and JIT strategies align with the maritime industry's decarbonization objectives, addressing both operational and environmental needs. Through improvements in anchoring and docking processes, the Port of Sines can contribute to the broader goal of sustainable port management, making it a model for medium-sized ports aiming to balance growth with environmental responsibility. The positive impact of JIT can be confirmed by the successful implementation at Tanger Med port, which highlights its significant positive influence on port operations, shipowners, and the environment, by ensuring efficient and timely docking [31].

Nevertheless, it is crucial to recognize that achieving the successful implementation of just-in-time (JIT) is inherently challenging. This is primarily due to the necessity for full commitment from all stakeholders involved, including management, employees, and suppliers. Additionally, effective JIT implementation requires the seamless sharing of critical information, which can be difficult to attain due to organizational barriers, confidentiality concerns, and the complexity of coordinating across multiple parties. These factors underscore the complexity of JIT adoption and the need for a well-coordinated, collaborative effort among all involved entities to overcome the inherent challenges [19].

4. Conclusions

The analysis of the obtained results for each of the terminals indicates that there are big differences between them. This demonstrates that the different concessionaires that manage each of the facilities and, more importantly, the type of cargo that is handled have a great impact on terminal dwell times.

Possibly, the main problem associated with the Port of Sines is the anchoring frequency. Despite not handling a huge number of vessels like other ports around the world, the port still has a significant number of vessels that anchor. However, some of these vessels only stay in the anchorage area for a short time (<3 h).

The navigation patterns in the Port of Sines between 2010 and 2023 show that Sines possesses a good dwell time (0.55) when compared to the top 25 world economies (1.16). Despite this, it is important to note that the port handles much fewer port calls than the ports considered in the largest economies studied. Taking this into account, it is not viable to affirm that the Port of Sines is more efficient than these ports, but it is safe to say that it is an efficient port. This efficiency could even be improved if the port managed to minimize anchoring frequency, which occurs 38% of the time when a vessel enters the port.

Although the results of this study were satisfactory, the analysis process encountered significant obstacles due to the lack of uniformity between the two databases. In particular, differences in terminology between the datasets caused substantial difficulties in interpreting, comparing, and integrating the information. In addition, the presence of incomplete data posed a challenge, which was resolved by removing this information, as it could distort the results or lead to incomplete conclusions. Overall, these obstacles highlight the need for greater consistency and improvements in data collection and organization. Resolving these issues could improve the effectiveness of these studies by making them regular in the port, in order to understand the evolution of the efficiency of operations.

For future work, we propose the development of parametric prediction models to analyze vessel time and movement, with a specific focus on incorporating port maneuvers. This comprehensive approach would integrate a comparative study between the Estimated Time of Arrival (ETA) and Actual Time of Arrival (ATA). Such investigations would offer valuable insights into the adaptability and scalability of JIT practices. Alternatively, future studies could also focus on refining the models by adjusting key parameters, incorporating advanced optimization techniques, and expanding the range of evaluated metrics. This would enhance the accuracy and robustness of predictive tools, enabling more efficient port operations. Furthermore, research could include a detailed quantitative analysis of delays and their root causes, which would provide deeper insights into operational inefficiencies, paving the way for targeted improvements. By pursuing these directions, studies can contribute to the development of more reliable predictive models, improved port management practices, and a better understanding of the interplay between operational and environmental factors in maritime logistics.

The implementation of just-in-time could be a key factor in reducing anchoring, since it allows (and requires) synchronization between all stakeholders, avoiding the arrival of vessels at a time when services and facilities are not fully available. If successful, it would be possible to improve the terminal times, especially in the Liquid Bulk and Petrochemical Terminals, where the anchoring frequency is higher. This implementation would also be essential to achieve more sustainable and productive vessel operations, reducing the generated emissions and fuel consumption.

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